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REPORT

OF THE

TESTS OF METALS

AND

OTHER MATERIALS

MADE AT THE

UNITED STATES TESTING LABORATORY AT WATERTOWN ARSENAL, MASSACHUSETTS, DURING THE FISCAL YEAR ENDED JUNE 30

1915

WASHINGTON
GOVERNMENT PRINTING OFFICE
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LETTER OF TRANSMITTAL.

WAR DEPARTMENT,
Washington, December 14, 1915.

SIR: I have the honor to transmit herewith the report of the commanding officer of Watertown Arsenal of "tests of iron and steel and other materials for industrial purposes" made at that arsenal during the fiscal year ended June 30, 1915, submitted by the Chief of Ordnance, United States Army, for transmission to Congress as required by law.

Very respectfully,

LINDLEY M. GARRISON,
Secretary of War.

The SPEAKER OF THE HOUSE OF REPRESENTATIVES.

WATERTOWN ARSENAL,
Watertown, Mass., October 19, 1915.

From: Commanding Officer, Watertown Arsenal.
To: Chief of Ordnance, United States Army, Washington, D. C.
Subject: Annual report of Tests of Metals, etc., for year ending June 30, 1915.

1. The annual report of tests of iron, steel, and other materials, made at this arsenal during the fiscal year ending June 30, 1915, is submitted herewith.

2. The total number of specimens tested during the year was 5,233, classified as follows:

For Ordnance Department	4,718
Other Government departments:	20
Private tests	495
Total	5,233

3. The receipts and expenditures were as follows:

Amount allotted for testing machines and testing work	$15,045.86
Received from private tests	770.75
Total received	15,816.61
Amount expended for services and labor	11,592.03
Amount expended for light, power, tools, implements, and material for test	4,224.58
Total expended	15,816.61

4. The equipment of the laboratory has been increased by the purchase of the following apparatus:

One Le Chatalier-Saladin autographic pyrometric recorder for photographically recording the temperature of transformations in metal.

One Gaede high vacuum mercury pump.

Three apochromatic objectives for Leitz micrometallograph.

One adjustable portrait camera stand.

One professional printing machine.

One power hack-saw.

5. The work of the laboratory may be divided into four classes: (1) Routine, (2) investigative, (3) research, (4) private.

The routine tests include such as are incidental to the operation of the arsenal, and include numerous tests on steel, cast-iron, bronze, rope, wood, chain, rubber, and proof stressing of gun carriage parts. Investigative tests include examination into the causes of defective material, and investigations for the improvement of ordnance material, the results of which have an immediate application. Research tests, on the other hand, are such tests as have no immediate con-

crete application, but improve our knowledge of the art and science of metallurgy, and furnish important and valuable data for future use. Private tests include all testing done for commercial concerns.

6. During the past year a greater number than usual of investigative and research tests have been completed, and it is believed that this report is especially interesting for that reason.

7. A pamphlet on the microscopic examination of steel was prepared for the use of inspectors of ordnance. The specifications for gun carriages and for oils were also revised during the year.

C. B. WHEELER,
Colonel, Ordnance Department, Commanding.

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REPORT

OF THE

TESTS OF METALS

AND

OTHER MATERIALS

MADE AT THE

UNITED STATES TESTING LABORATORY AT WATERTOWN ARSENAL, MASSACHUSETTS, DURING THE FISCAL YEAR ENDED JUNE 30, 1915.

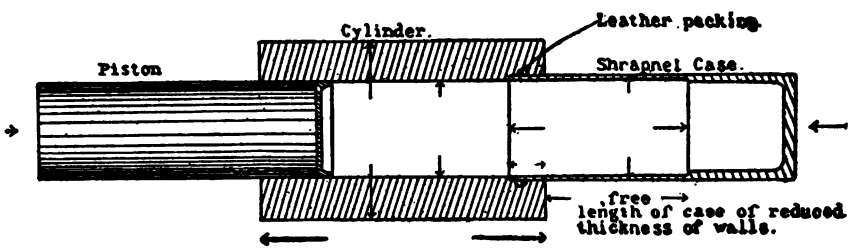
SHRAPNEL CASES.

HYDROSTATIC TESTS OF 27 SHRAPNEL CASES FOR FRANKFORD ARSENAL.

These shrapnel cases were received from Frankford Arsenal and were manufactured from heat treated bar stock purchased by that arsenal. They represent material from which shrapnel cases that passed the prescribed ballistic tests were made.

These cases were all tested by internal hydrostatic pressure by means of the fixture shown on this page.

TESTING ATTACHMENT.



FIRST CASE.—2.95-INCH SHRAPNEL CASE A-1.

Chemical analysis.

C	0.546
Mn	.75
Si	.072
S	.026
P	.027
Ni	1.15

Case etched with iodine.
Short streaks visible in case before testing.
Outside diameter of case, 2.92 inches.
Inside diameter of case, 2.62 inches.
Length of threaded section at top, 0.50 inches.
Bored out for a length of 5.10 inches.
Depth inside, 6.82 inches.
Length over all, outside, 7.15 inches.
Length from top to top edge of band groove, 5.40 inches.
Case entered testing cylinder 1½ inches, leaving 3.60 inches length of reduced thickness of walls exposed to the interior pressure of the test.
Diameter of piston, 2.62 inches.
Sectional area, 5.39 square inches.

Applied loads.			Remarks.
Total pounds on piston.	Interior pressure (pounds per square inch).	Fiber stress on case (pounds per square inch).	
77,100	14,300	125,000	Ultimate strength.

Longitudinal rupture. Fracture started at a silky spot near the middle of case.
There were a few internal streaks visible in fracture.
Appearance of fracture, fine granular.

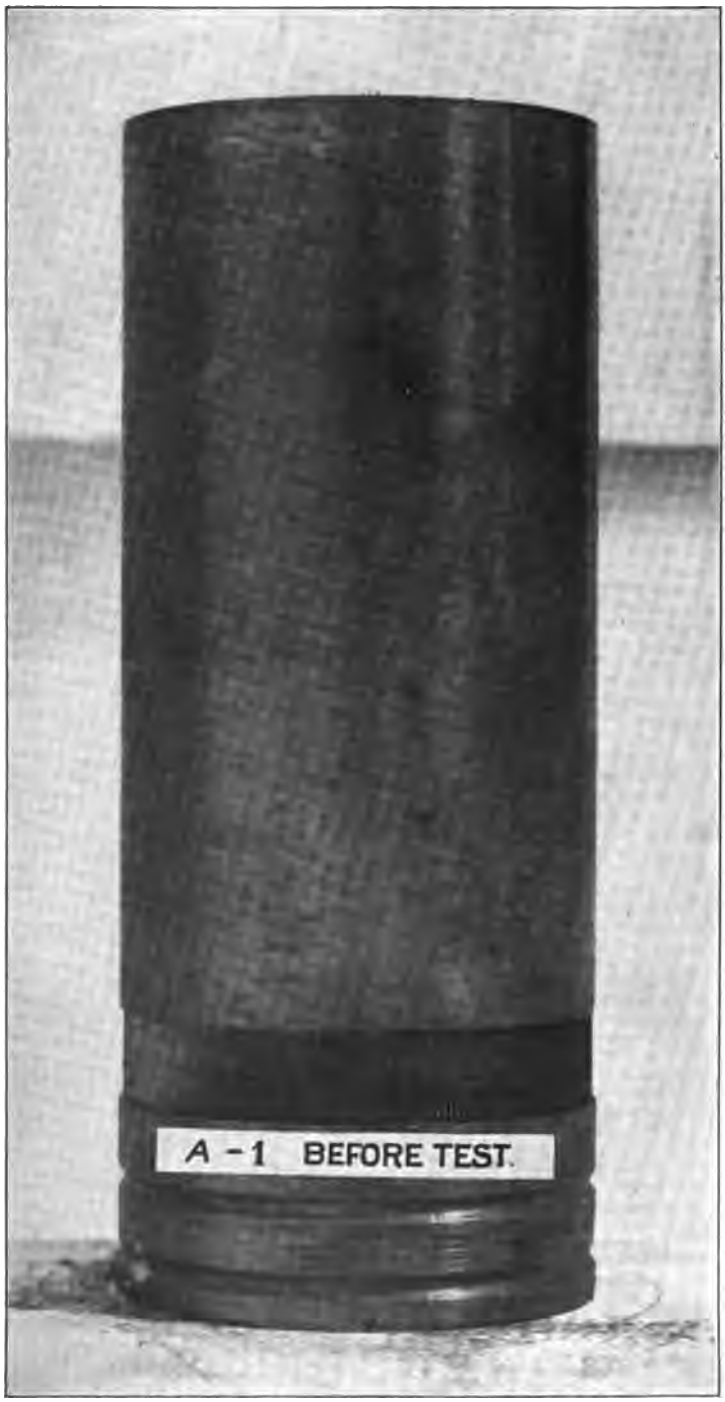
SECOND CASE.—2.95-INCH SHRAPNEL CASE A-2.

(Chemical analysis, see Case A-1.)

Case etched with iodine.
Short streaks visible in case before testing.
Outside diameter of case, 2.92 inches.
Inside diameter of case, 2.62 inches.
Length of threaded section at top, 0.55 inch.
Bored out for length of 5.10 inches.
Depth inside, 6.83 inches.
Length over all outside, 7.16 inches.
Length from top to top edge of band groove, 5.38 inches.
Case entered testing cylinder 1½ inches, leaving 3.60 inches length of reduced thickness of walls exposed to the interior pressure of the test.
Diameter of piston, 2.62 inches.
Sectional area, 5.39 square inches.

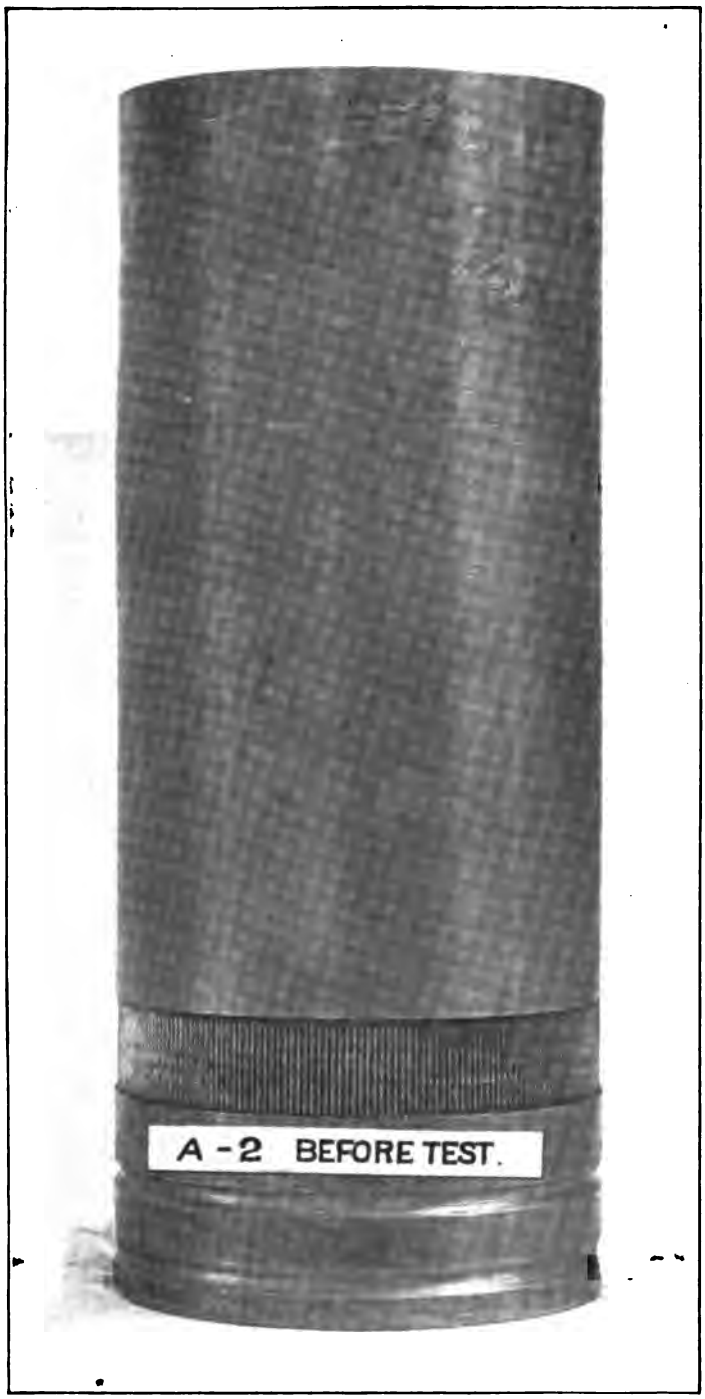
Applied loads.			Remarks.
Total pounds on piston.	Interior pressure (pounds per square inch).	Fiber stress on case (pounds per square inch).	
66,200	12,280	107,100	Ultimate strength.

Longitudinal rupture. Fracture started at a lamellar streak a little below the middle of case, extending down and partly through the base. Case shows a little ductility.
Appearance of fracture, silky and fine granular.



2.95-INCH SHRAPNEL CASE MADE FROM BAR STOCK. NO. A-1.

2.95-INCH SHRAPNEL CASE MADE FROM BAR STOCK. NO. A-1.



2.95-INCH SHRAPNEL CASE MADE FROM BAR STOCK. NO. A-2.

A -2 AFTER TEST

THIRD CASE.—2.95-INCH SHRAPNEL CASE A-3.

(Chemical analysis, see Case A-1.)

Case etched with iodine.
Short streaks visible in case before testing.
Outside diameter of case, 2.92 inches.
Inside diameter of case, 2.62 inches.
Length of threaded section at top, 0.55 inch.
Bored out for a length of 5.10 inches.
Depth inside, 6.85 inches.
Length over all outside, 7.16 inches.
Length from top to top edge of band groove, 5.40 inches.
Case entered testing cylinder 1½ inches, leaving 3.60 inches length of reduced thickness of walls exposed to the interior pressure of the test.
Diameter of piston, 2.62 inches.
Sectional area, 5.39 square inches.

Applied loads.			Remarks.
Total pounds on piston.	Interior pressure (pounds per square inch).	Fiber stress on case (pounds per square inch).	
84,500	15,680	136,900	Ultimate strength.

Longitudinal rupture. Fracture started at a little above the middle of case, extending down and partly through the base.
Appearance of fracture, silky and fine granular.

FOURTH CASE.—3-INCH SHRAPNEL CASE A-4.

Chemical analysis.

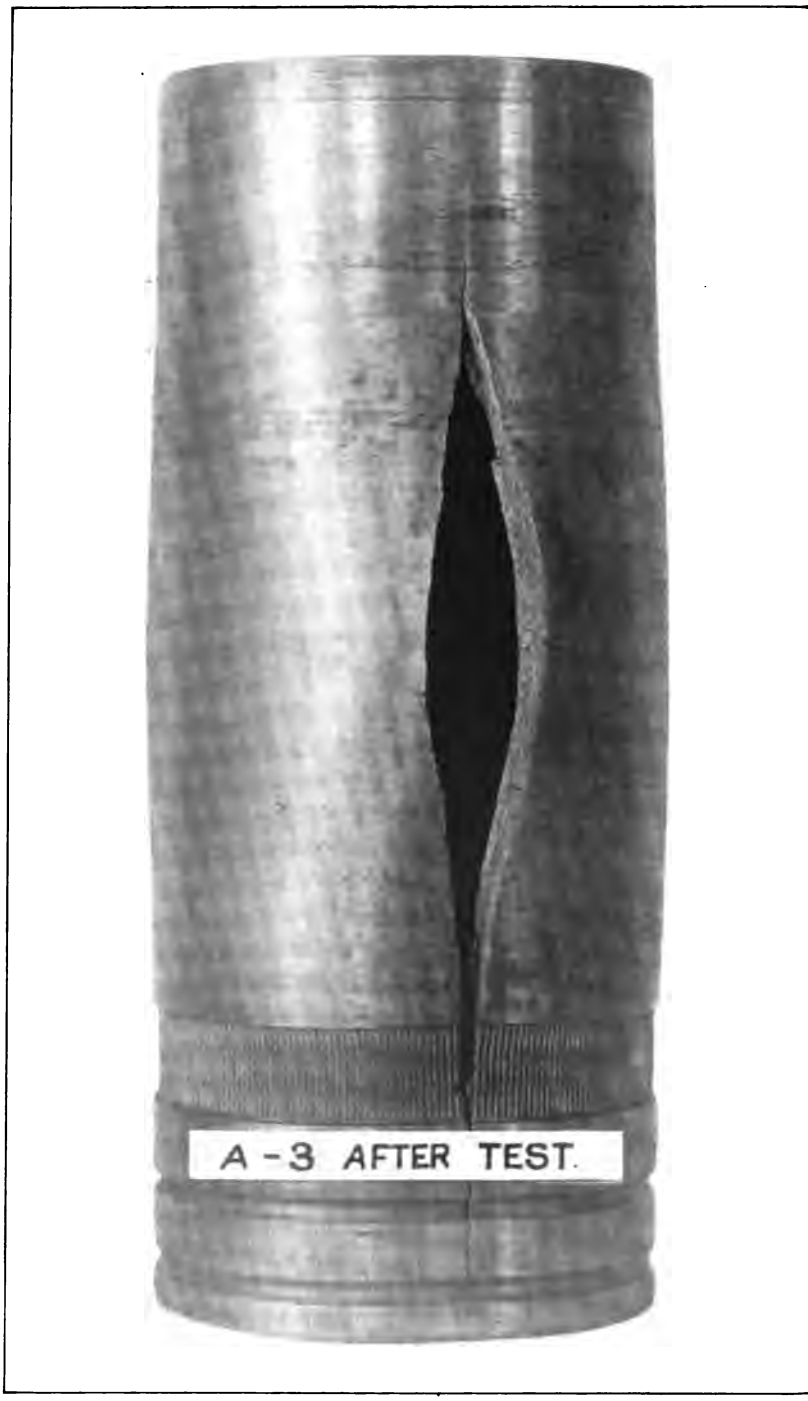
C	0.426
Mn	.71
Si	.181
S	.011
P	.025
Ni	1.20
Cr	.74

Case etched with iodine.
Short streaks were visible in case before testing.
Outside diameter of case, 2.97 inches.
Inside diameter of case, 2.63 inches.
Length of threaded section at top: Not threaded.
Bored out for a length of 5.53 inches.
Depth inside, 7.00 inches.
Length over all outside, 7.40 inches.
Length from top to top edge of band groove, 5.63 inches.
Case entered testing cylinder 1 inch, leaving 4.53 inches length of reduced thickness of walls exposed to the interior pressure of the test.
Diameter of piston, 2.62 inches.
Sectional area, 5.39 square inches.

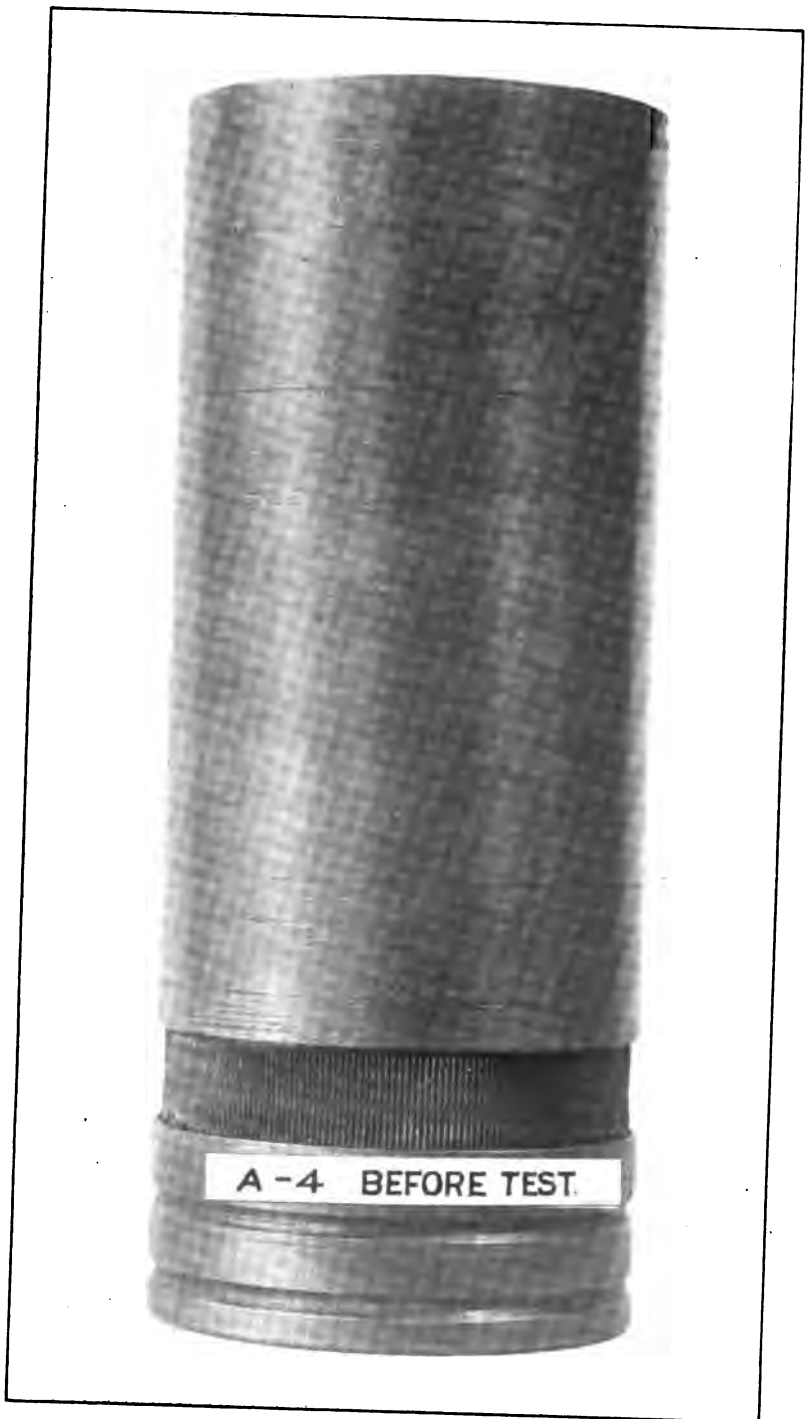
Applied loads.			Remarks.
Total pounds on piston.	Interior pressure (pounds per square inch).	Fiber stress on case (pounds per square inch).	
88,400	16,400	127,040	Ultimate strength.

Longitudinal rupture.
Fracture started a little above the middle of case.
No streaks or seams visible in fracture.
Appearance of fracture, silky and lamellar.
Small check developed in case $1\frac{5}{8}$ inches from top and $\frac{1}{2}$ inch from fracture.

2.95-INCH SHRAPNEL CASE MADE FROM BAR STOCK. NO. A-3.



2.95-INCH SHRAPNEL CASE MADE FROM BAR STOCK. NO. A-3.



3-INCH SHRAPNEL CASE MADE FROM BAR STOCK. NO. A-4.

3-INCH SHRAPNEL CASE MADE FROM BAR STOCK. NO. A-4.

FIFTH CASE.—3-INCH SHRAPNEL CASE A-5.

(Chemical analysis, see Case A-4.)

Case etched with iodine.
Short streaks were visible in case before testing.
Outside diameter of case, 2.97 inches.
Inside diameter of case, 2.63 inches.
Length of threaded section at top: Not threaded.
Bored out for a length of 5.54 inches.
Depth inside, 7.04 inches.
Length over all outside, 7.41 inches.
Length from top to top edge of band groove, 5.66 inches.
Case entered testing cylinder 1 inch, leaving 4.54 inches length of reduced thickness of walls exposed to the interior pressure of the test.
Diameter of piston, 2.62 inches.
Sectional area, 5.39 square inches.

Applied loads.			Remarks.
Total pounds on piston.	Interior pressure (pounds per square inch).	Fiber stress on case (pounds per square inch).	
90,300	16,753	129,775	Ultimate strength.

Longitudinal rupture.
Fracture started near the top of case.
Short streak visible in fracture.
Appearance of fracture, silky and lamellar.

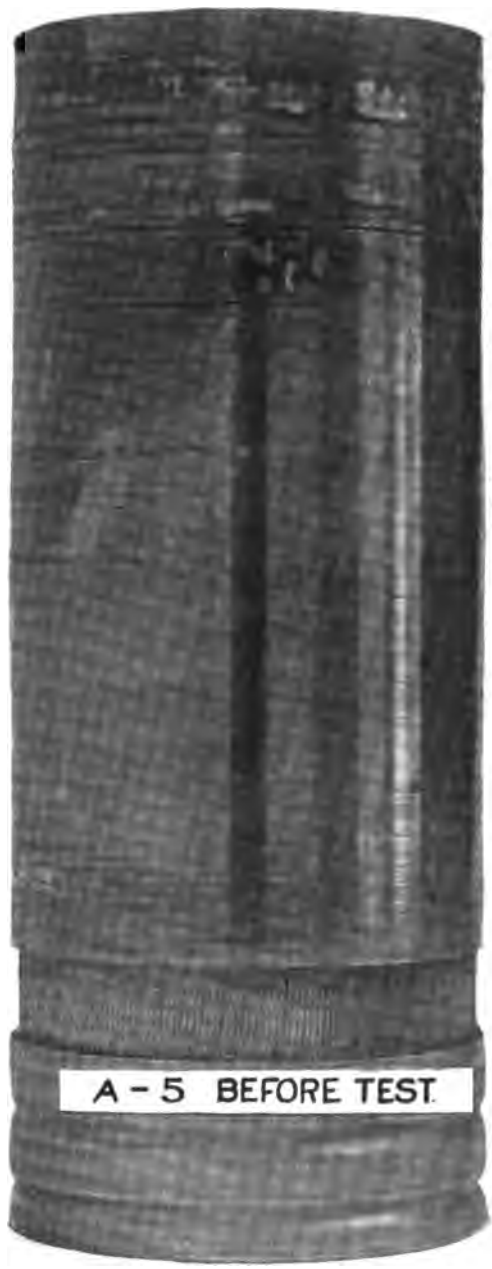
SIXTH CASE.—3-INCH SHRAPNEL CASE A-6.

(Chemical analysis, see Case A-4.)

Case etched with iodine.
No streaks visible in case before testing.
Outside diameter of case, 2.97 inches.
Inside diameter of case, 2.63 inches.
Length of threaded section at top: Not threaded.
Bored out for a length of 5.55 inches.
Depth inside, 7.00 inches.
Length over all outside, 7.40 inches.
Length from top to top edge of band groove, 5.63 inches.
Case entered testing cylinder 1 inch, leaving 4.55 inches length of reduced thickness of walls exposed to the interior pressure of the test.
Diameter of piston, 2.62 inches.
Sectional area, 5.39 square inches.

Applied loads.			Remarks.
Total pounds on piston.	Interior pressure (pounds per square inch).	Fiber stress on case (pounds per square inch).	
85,700	15,900	123,164	Ultimate strength.

Longitudinal rupture.
Fracture started at a lamellar spot about the middle of case.
Streaks visible in fracture.
Appearance of fracture, silky and granular.



3-INCH SHRAPNEL CASE MADE FROM BAR STOCK. No. A-5.

3-INCH SHRAPNEL CASE MADE FROM BAR STOCK. NO. A-5.

3-INCH SHRAPNEL CASE MADE FROM BAR STOCK. NO. A-6.

3-INCH SHRAPNEL CASE MADE FROM BAR STOCK. NO. A-6.

SEVENTH CASE.—3-INCH SHRAPNEL CASE B-1.

Chemical analysis.

C	0.438
Mn	.45
Si	.260
S	.021
P	.030
Ni	.37

Case etched with iodine.
No streaks visible in case before testing.
Outside diameter of case, 2.97 inches.
Inside diameter of case, 2.63 inches.
Length of threaded section at top: Not threaded.
Bored out for a length of 5.54 inches.
Depth inside, 7.03 inches.
Length over all outside, 7.41 inches.
Length from top to top edge of band groove, 5.65 inches.
Case entered testing cylinder 1 inch, leaving 4.54 inches length of reduced thickness of walls exposed to the interior pressure of the test.
Diameter of piston, 2.62 inches.
Sectional area, 5.39 square inches.

Applied loads.			Remarks.
Total pounds on piston.	Interior pressure (pounds per square inch).	Fiber stress on case (pounds per square inch).	
82,500	15,306	118,565	Ultimate strength.

Longitudinal rupture.
Fracture started at a spot at about the middle of case and extended down through a part of the base.
Appearance of fracture, fine granular.
Several short checks developed in different parts of the case during the test. Case tore around band groove at one side.

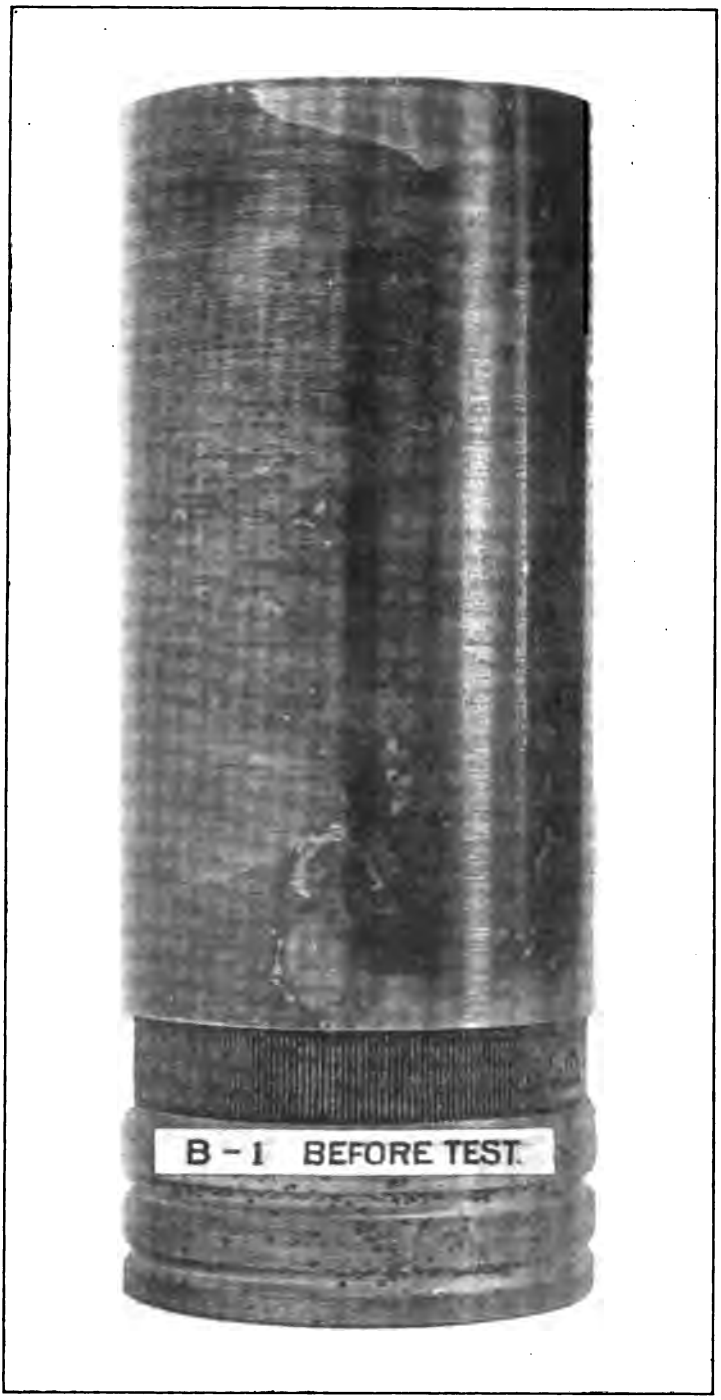
EIGHTH CASE.—3-INCH SHRAPNEL CASE B-2.

(Chemical analysis, see case B-1.)

Case etched with iodine.
A few very short streaks visible in case before testing.
Outside diameter of case, 2.97 inches.
Inside diameter of case, 2.63 inches.
Length of threaded section at top: Not threaded.
Bored out for a length of 5.53 inches.
Depth inside, 7.00 inches.
Length over all outside, 7.42 inches.
Length from top to top edge of band groove, 5.67 inches.
Case entered testing cylinder 1 inch, leaving 4.53 inches length of reduced thickness of walls exposed to the interior pressure of the test.
Diameter of piston, 2.62 inches.
Sectional area, 5.39 square inches.

Applied loads.			Remarks.
Total pounds on piston.	Interior pressure (pounds per square inch).	Fiber stress on case (pounds per square inch).	
85,700	15,900	123,164	Ultimate strength.

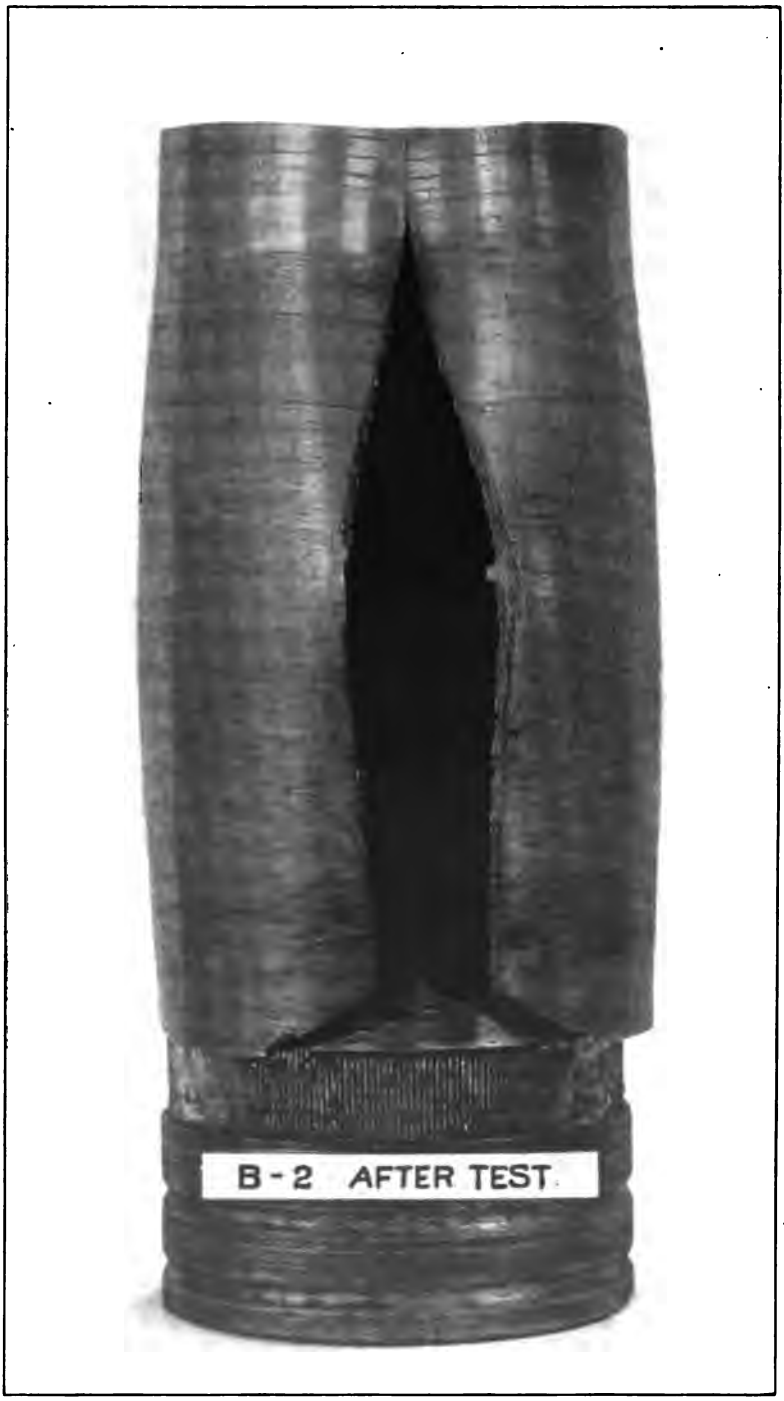
Longitudinal rupture.
Fracture started at a silky spot a little above the middle of case.
No internal streaks visible in fracture.
Appearance of fracture, fine granular. Case tore around band groove.



3-INCH SHRAPNEL CASE MADE FROM BAR STOCK. NO. B-1.

3-INCH SHRAPNEL CASE MADE FROM BAR STOCK. NO. B-1.

3-INCH SHRAPNEL CASE MADE FROM BAR STOCK. NO. B-2.



3-INCH SHRAPNEL CASE MADE FROM BAR STOCK. NO. B-2.

NINTH CASE.—3-INCH SHRAPNEL CASE B-3.

(Chemical analysis, see case B-1.)

Case etched with iodine.
No streaks visible in case before testing.
Outside diameter of case, 2.97 inches.
Inside diameter of case, 2.63 inches.
Length of threaded section at top: Not threaded.
Bored out for a length of 5.54 inches.
Depth inside, 7.01 inches.
Length over all outside, 7.41 inches.
Length from top to top edge of band groove, 5.65 inches.
Case entered testing cylinder 1 inch, leaving 4.54 inches length of reduced thickness of walls exposed to the interior pressure of the test.
Diameter of piston, 2.62 inches.
Sectional area, 5.39 square inches.

Applied loads.			Remarks.
Total pounds on piston.	Interior pressure (pounds per square inch).	Fiber stress on case (pounds per square inch).	
85,300	15,825	122,589	Ultimate strength.

Longitudinal rupture.
Fracture started at a lamellar spot about the middle of case.
No streak visible in fracture.
Appearance of fracture, fine granular.
Case tore around band groove.

TENTH CASE.—3-INCH SHRAPNEL CASE B-4.

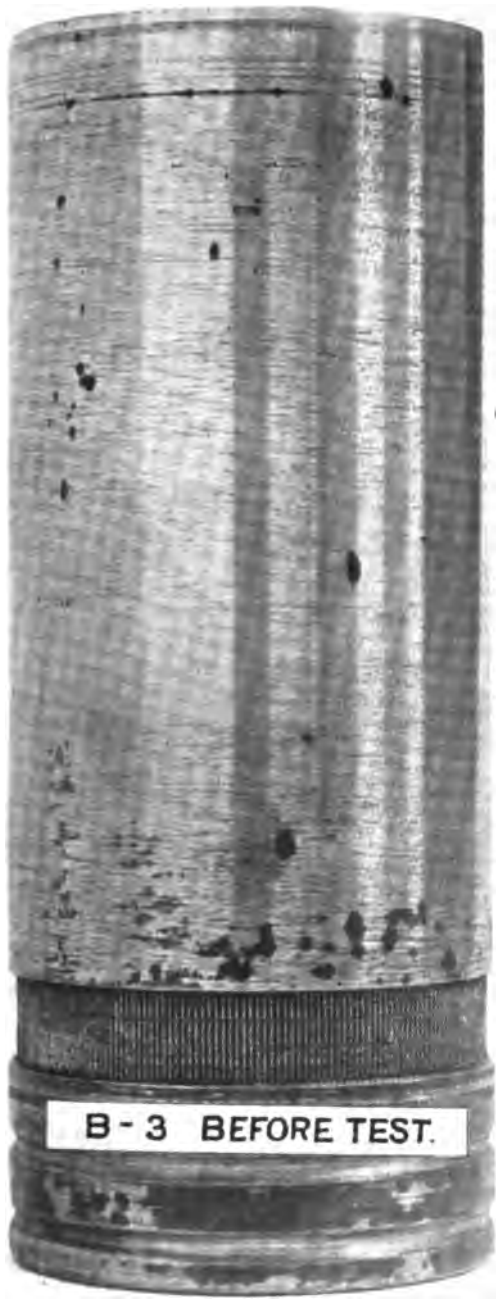
Chemical analysis.

C	0.464
Mn	.75
Si	.161
S	.033
P	.036
Ni	1.14

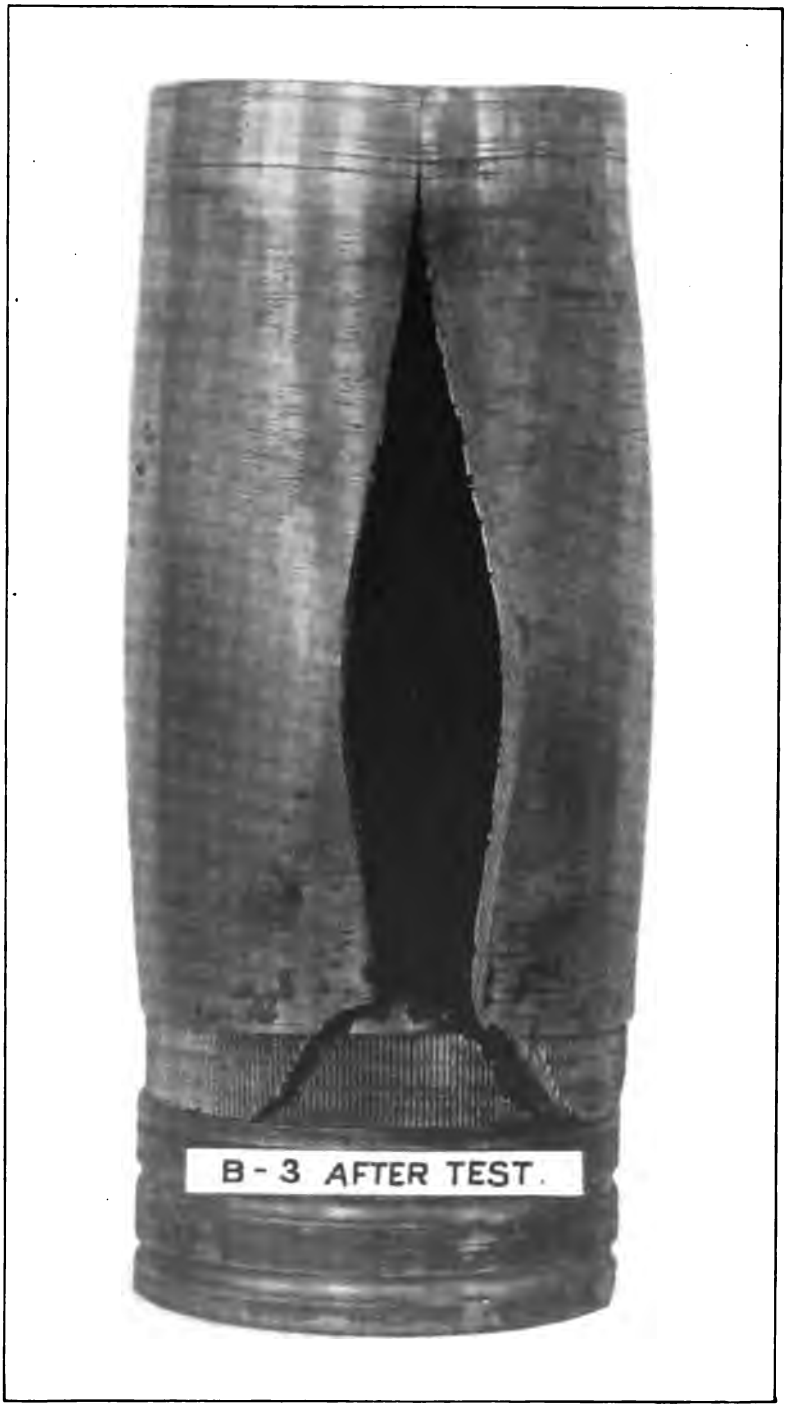
Case etched with iodine.
No streaks visible in case before testing.
Outside diameter of case, 2.97 inches.
Inside diameter of case, 2.63 inches.
Length of threaded section at top: Not threaded.
Bored out for a length of 5.53 inches.
Depth inside, 7.02 inches.
Length over all outside, 7.40 inches.
Length from top to top edge of band groove, 5.65 inches.
Case entered testing cylinder 1 inch, leaving 4.53 inches length of reduced thickness of walls exposed to the interior pressure of the test.
Diameter of piston, 2.62 inches.
Sectional area, 5.39 square inches.

Applied loads.			Remarks.
Total pounds on piston.	Interior pressure (pounds per square inch).	Fiber stress on case (pounds per square inch).	
89,900	16,679	129,200	Ultimate strength.

Longitudinal rupture.
Fracture started at a silky spot near the top of case.
No streaks visible in fracture.
Appearance of fracture, fine granular.
Case tore around band groove. Fragment nearly detached.



3-INCH SHRAPNEL CASE MADE FROM BAR STOCK. NO. B-3.



3-INCH SHRAPNEL CASE MADE FROM BAR STOCK. NO. B-3.

3-INCH SHRAPNEL CASE MADE FROM BAR STOCK. NO. B-4.

3-INCH SHRAPNEL CASE MADE FROM BAR STOCK. NO. B-4.

ELEVENTH CASE.—3-INCH SHRAPNEL CASE B–5.

(Chemical analysis, see Case B–1.)

Case etched with iodine.
Short streaks visible in case before testing.
Outside diameter of case, 2.97 inches.
Inside diameter of case, 2.63 inches.
Length of threaded section at top: Not threaded.
Bored out for a length of 5.52 inches.
Depth inside, 7.03 inches.
Length over all outside, 7.41 inches.
Length from top to top edge of band groove, 5.65 inches.
Case entered testing cylinder 1 inch, leaving 4.52 inches length of reduced thickness of walls exposed to the interior pressure of the test.
Diameter of piston, 2.62 inches.
Sectional area, 5.39 square inches.

Applied loads.			Remarks.
Total pounds on piston.	Interior pressure (pounds per square inch).	Fiber stress on case (pounds per square inch).	
95,500	17,718	137,248	Ultimate strength.

Longitudinal rupture.
Fracture started at a lamellar spot near the middle of case.
No streaks visible in fracture.
Two fragments 4.5 inches long by about 2 inches wide were detached from the case.
Appearance of fracture, fine granular.
Several short checks developed in one of the fragments during the test.

TWELFTH CASE.—3-INCH SHRAPNEL CASE B-6.

Chemical analysis.

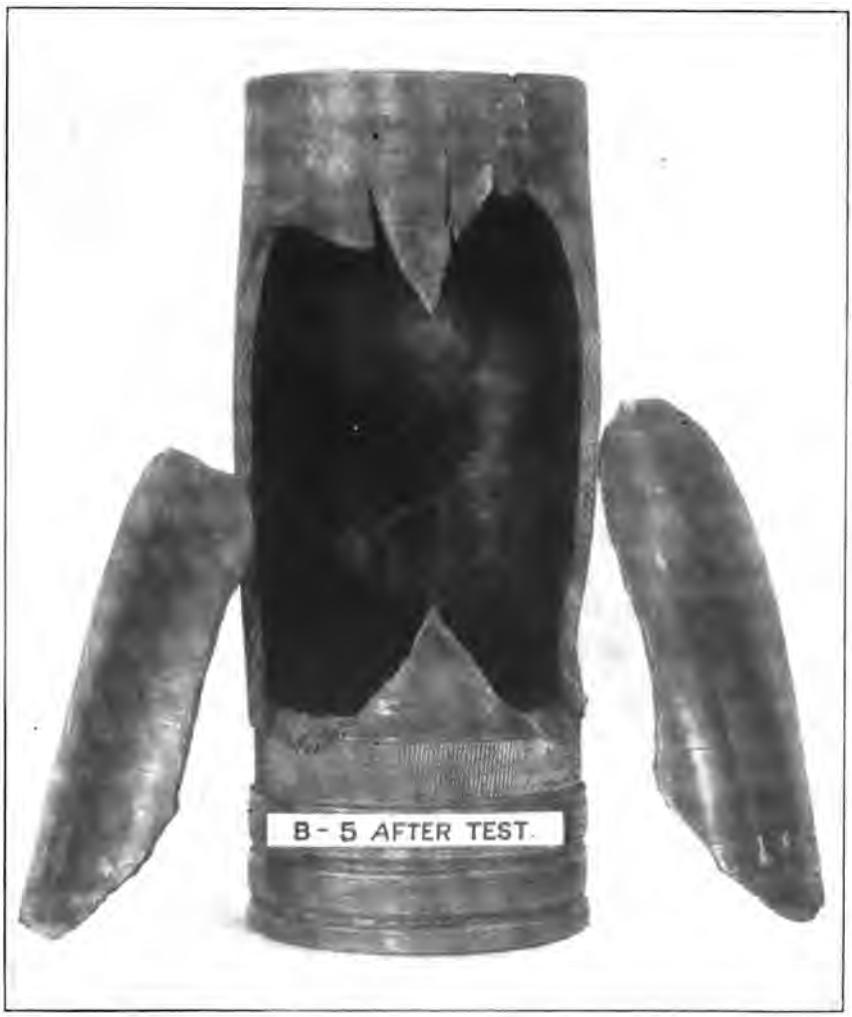
C	0.512
Mn	0.73
Si	0.37
S	0.028
P	0.026
Ni	1.45

Case etched with iodine.
No streaks were visible in case before testing.
Outside diameter of case, 2.97 inches.
Inside diameter of case, 2.63 inches.
Length of threaded section at top: Not threaded.
Bored out for a length of 5.53 inches.
Depth inside, 7.02 inches.
Length over all outside, 7.40 inches.
Length from top to top edge of band groove, 5.65 inches.
Case entered testing cylinder 1 inch, leaving 4.53 inches length of reduced thickness of walls exposed to the interior pressure of the test.
Diameter of piston, 2.62 inches.
Sectional area, 5.39 square inches.

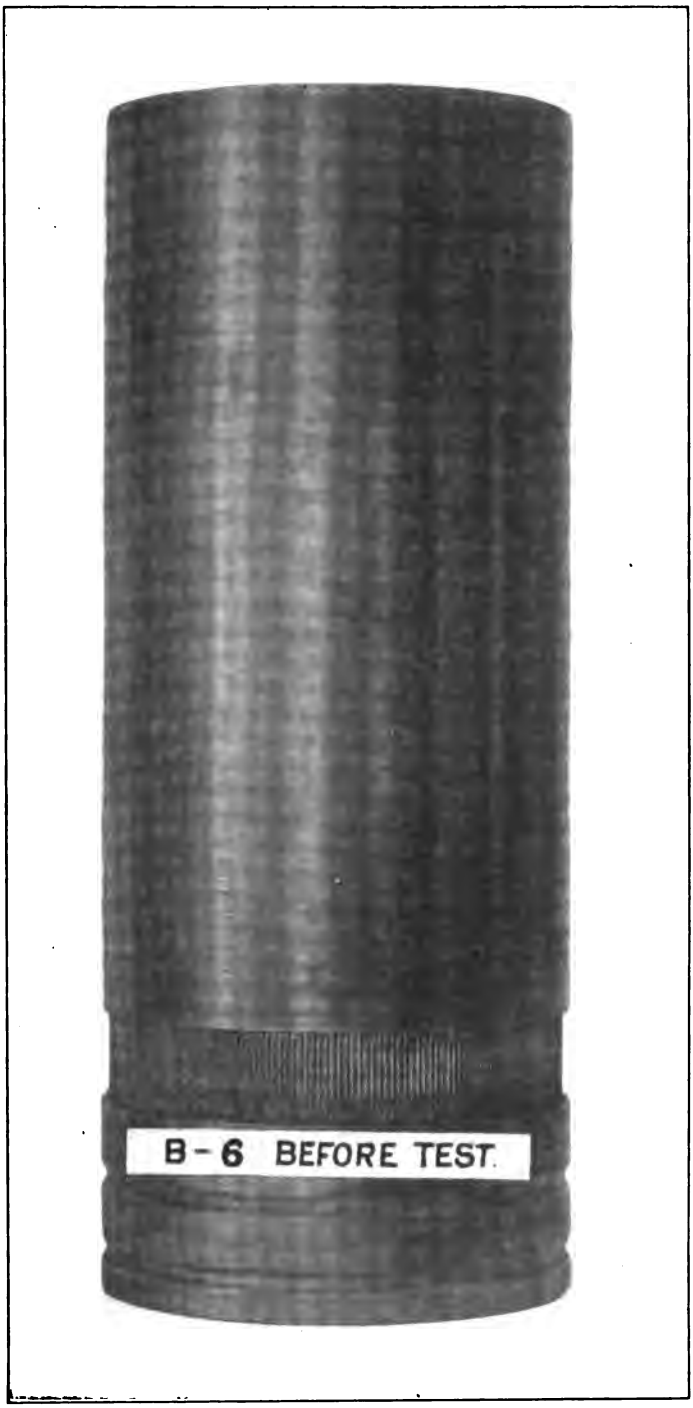
Applied loads.			Remarks.
Total pounds on piston.	Interior pressure (pounds per square inch).	Fiber stress on case (pounds per square inch).	
84,800	15,732	121,871	Ultimate strength.

Longitudinal rupture.
Fracture started near the top of the case, extending down through the base and up on the opposite side to within 1¼ inches from top.
Fragment 2½ inches long by about ⅜ inch wide was detached from the case.
No streaks visible in fracture.
Appearance of fracture, medium coarse granular.

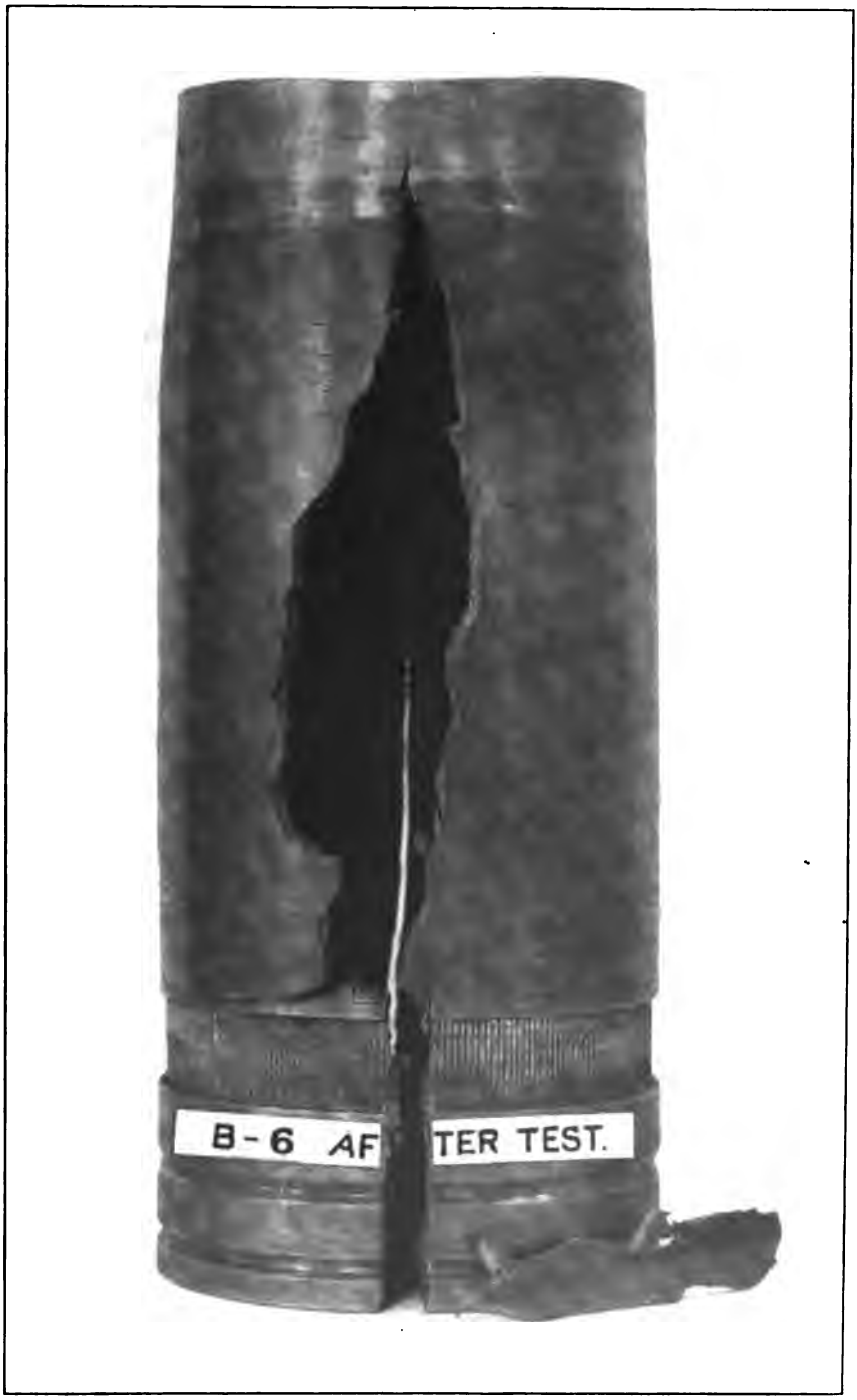
3-INCH SHRAPNEL CASE MADE FROM BAR STOCK. NO. B-5.



3-INCH SHRAPNEL CASE MADE FROM BAR STOCK. NO. B-5.



3-INCH SHRAPNEL CASE MADE FROM BAR STOCK. NO. B-6.



3-INCH SHRAPNEL CASE MADE FROM BAR STOCK. NO. B-6.

THIRTEENTH CASE.—3-INCH SHRAPNEL CASE C-1.

Chemical analysis.

C	0.468
Mn	0.68
Si	0.180
S	0.031
P	0.017
Ni	1.11

Case etched with iodine.
Streaks visible before testing.
Outside diameter of case, 2.97 inches.
Inside diameter of case, 2.63 inches.
Length of threaded section at top, 0.55 inch.
Bored out for a length of 5.50 inches.
Depth inside, 7.00 inches.
Length over all outside, 7.41 inches.
Length from top to top edge of band groove, 5.65 inches.
Case entered testing cylinder 1 inch, leaving 4.50 inches length of reduced thickness of walls exposed to the interior pressure of the test.
Diameter of piston, 2.62 inches.
Sectional area, 5.39 square inches.

Applied loads.			Remarks.
Total pounds on piston.	Interior pressure (pounds per square inch).	Fiber stress on case (pounds per square inch).	
79,600	14,768	114,397	Ultimate strength.

Longitudinal rupture.
Fracture started near the middle of case.
Internal streaks visible in fracture.
Appearance of fracture, lamellar.

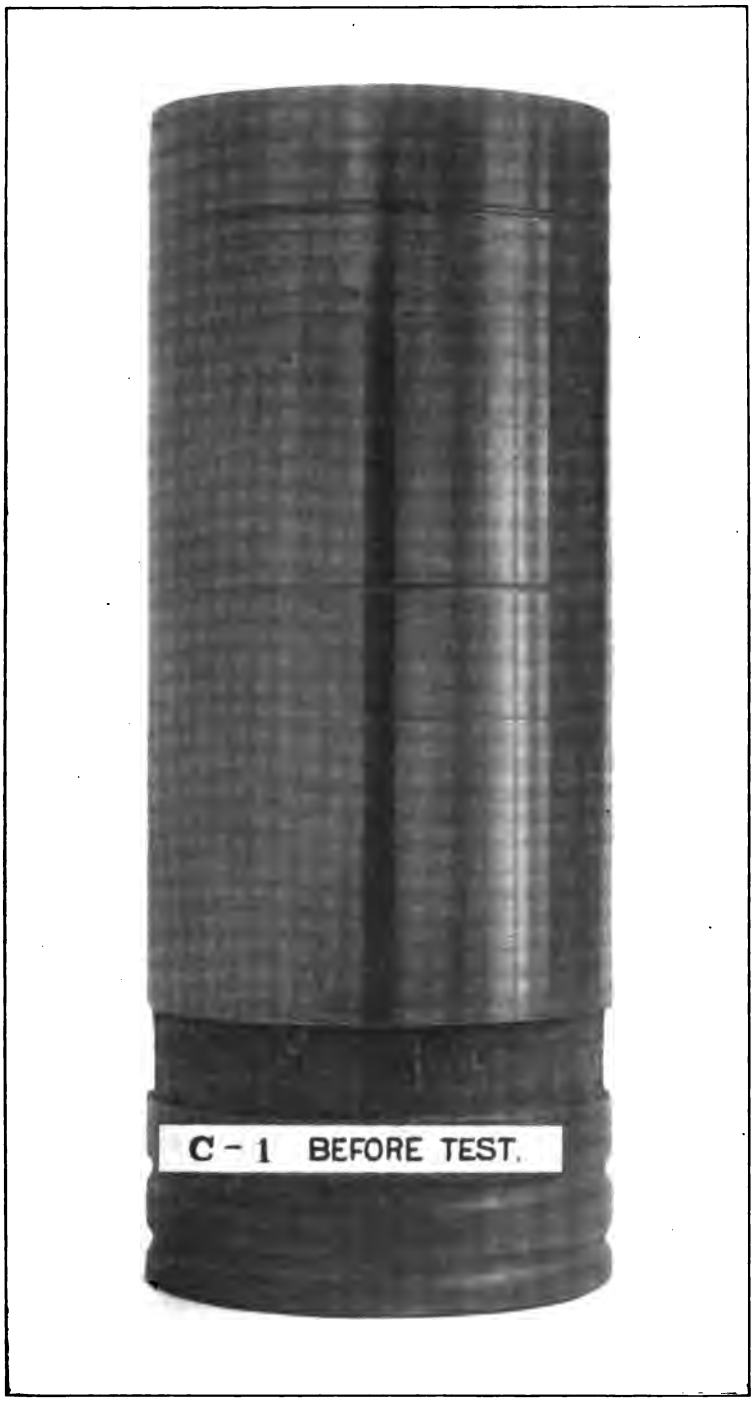
FOURTEENTH CASE.—3-INCH SHRAPNEL CASE C-2.

(Chemical analysis, see Case C-1.)

Case etched with iodine.
Short streaks visible in case before testing.
Outside diameter of case, 2.97 inches.
Inside diameter of case, 2.63 inches.
Length of threaded section at top, 0.55 inch.
Bored out for a length of 5.50 inches.
Depth inside, 7.00 inches.
Length over all outside, 7.40 inches.
Length from top to top edge of band groove, 5.65 inches.
Case entered testing cylinder 1 inch, leaving 4.50 inches length of reduced thickness of walls exposed to the interior pressure of the test.
Diameter of piston, 2.62 inches.
Sectional area, 5.39 square inches.

Applied loads.			Remarks.
Total pounds on piston.	Interior pressure (pounds per square inch).	Fiber stress on case (pounds per square inch).	
85,400	15,844	122,733	Ultimate strength.

Longitudinal rupture.
Fracture started near the top of the case.
No streaks visible in fracture.
Appearance of fracture, silky and lamellar.



3-INCH SHRAPNEL CASE MADE FROM BAR STOCK. NO. C-1.

3-INCH SHRAPNEL CASE MADE FROM BAR STOCK. NO. C-1.

3-INCH SHRAPNEL CASE MADE FROM BAR STOCK. NO. C-2.

3-INCH SHRAPNEL CASE MADE FROM BAR STOCK. NO. C-2.

FIFTEENTH CASE.—3-INCH SHRAPNEL CASE C-3.

(Chemical analysis, see Case C-1.)

Case etched with iodine.
Long streaks were visible in case before testing.
Outside diameter of case, 2.97 inches.
Inside diameter of case, 2.63 inches.
Length of threaded section at top, 0.55 inch.
Bored out for a length of 5.50 inches.
Depth inside, 7.00 inches.
Length over all outside, 7.40 inches.
Length from top to top edge of band groove, 5.65 inches.
Case entered testing cylinder 1 inch, leaving 4.50 inches length of reduced thickness of walls exposed to the interior pressure of the test.
Diameter of piston, 2.62 inches.
Sectional area, 5.39 square inches.

Applied loads.			Remarks.
Total pounds on piston.	Interior pressure (pounds per square inch).	Fiber stress on case (pounds per square inch).	
88,900	16,493	127,763	Ultimate strength.

Longitudinal rupture.
Fracture started near the middle of case at an external streak.
Internal streak visible in fracture.
Appearance of fracture, silky and lamellar.

SIXTEENTH CASE.—3-INCH SHRAPNEL CASE C-4.

Chemical analysis.

C	0.468
Mn	.66
Si	.143
S	.030
P	.015
Ni	1.10

Case etched with iodine.
Short streaks visible in case before testing.
Outside diameter of case, 2.97 inches.
Inside diameter of case, 2.63 inches.
Length of threaded section at top: Not threaded.
Bored out for a length of 5.53 inches.
Depth inside, 7.02 inches.
Length over all outside, 7.42 inches.
Length from top to top edge of band grooves, 5.65 inches.
Case entered testing cylinder 1.00 inch, leaving 4.53 inches length of reduced thickness of walls exposed to the interior pressure of the test.
Diameter of piston, 2.62 inches.
Sectional area, 5.39 square inches.

Applied loads.			Remarks.
Total pounds on piston.	Interior pressure (pounds per square inch).	Fiber stress on case (pounds per square inch).	
78,200	14,508	112,263	Ultimate strength.

3-INCH SHRAPNEL CASE MADE FROM BAR STOCK. NO. C-3.

3-INCH SHRAPNEL CASE MADE FROM BAR STOCK. NO. C-3.

3-INCH SHRAPNEL CASE MADE FROM BAR STOCK. NO. C-4.

3-INCH SHRAPNEL CASE MADE FROM BAR STOCK. NO. C-4.

Longitudinal rupture.
Fracture started at about the middle of case.
Short internal streaks visible in fracture.
Appearance of fracture, lamellar.

SEVENTEENTH CASE.—3-INCH SHRAPNEL CASE C-5.

(Chemical analysis, see case C-4.)

Case etched with iodine.
Streaks visible in case before testing.
Outside diameter of case, 2.97 inches.
Inside diameter of case, 2.63 inches.
Length of threaded section at top: Not threaded.
Bored out for a length of 5.52 inches.
Depth inside, 7.00 inches.
Length over all outside, 7.41 inches.
Length from top to top edge of band groove, 5.65 inches.
Case entered testing cylinder 1 inch, leaving 4.52 inches length of reduced thickness of walls exposed to the interior pressure of the test.
Diameter of piston, 2.62 inches.
Sectional area, 5.39 square inches

Applied loads.			Remarks.
Total pounds on piston.	Interior pressure (pounds per square inch).	Fiber stress on case (pounds per square inch).	
82,100	15,232	117,990	Ultimate strength.

Longitudinal rupture.
Fracture started near the top of case.
Long internal streaks visible in fracture.
Appearance of fracture, lamellar.

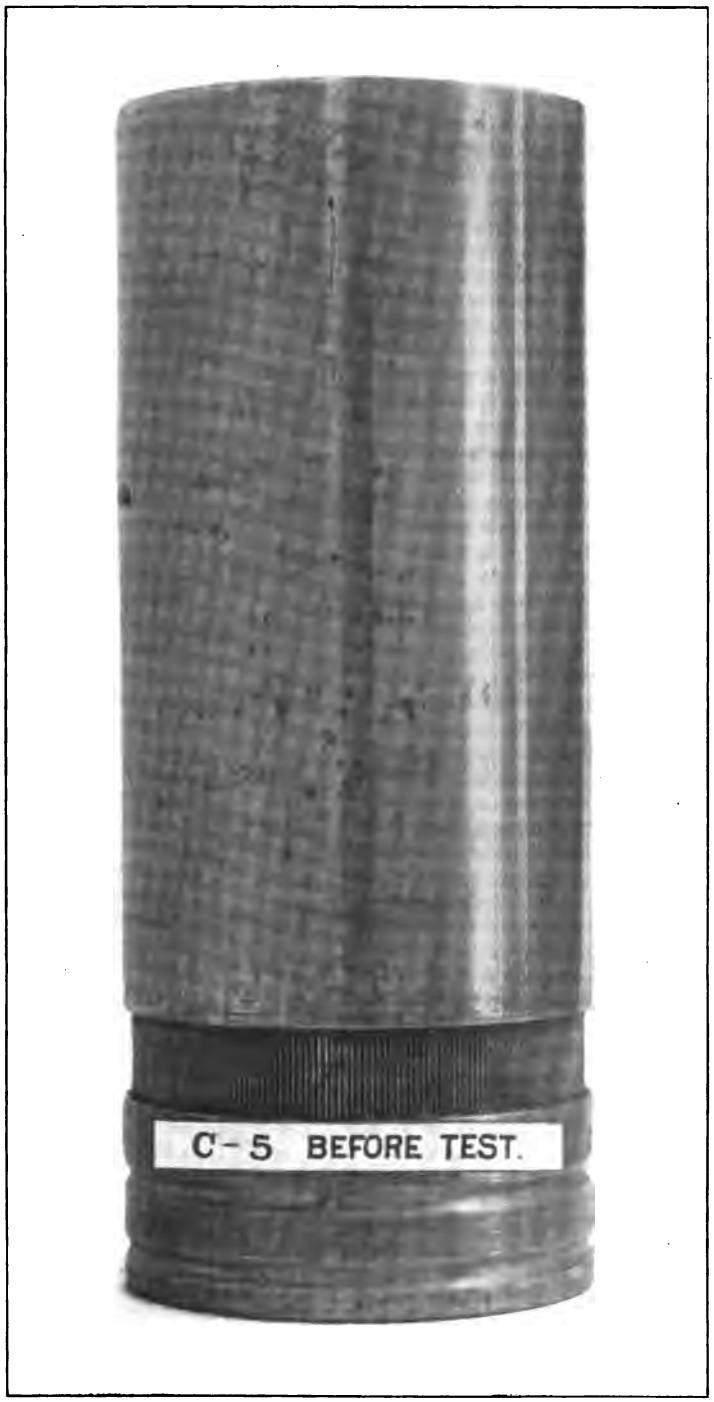
EIGHTEENTH CASE.—3-INCH SHRAPNEL CASE C-6.

(Chemical analysis, see case C-4.)

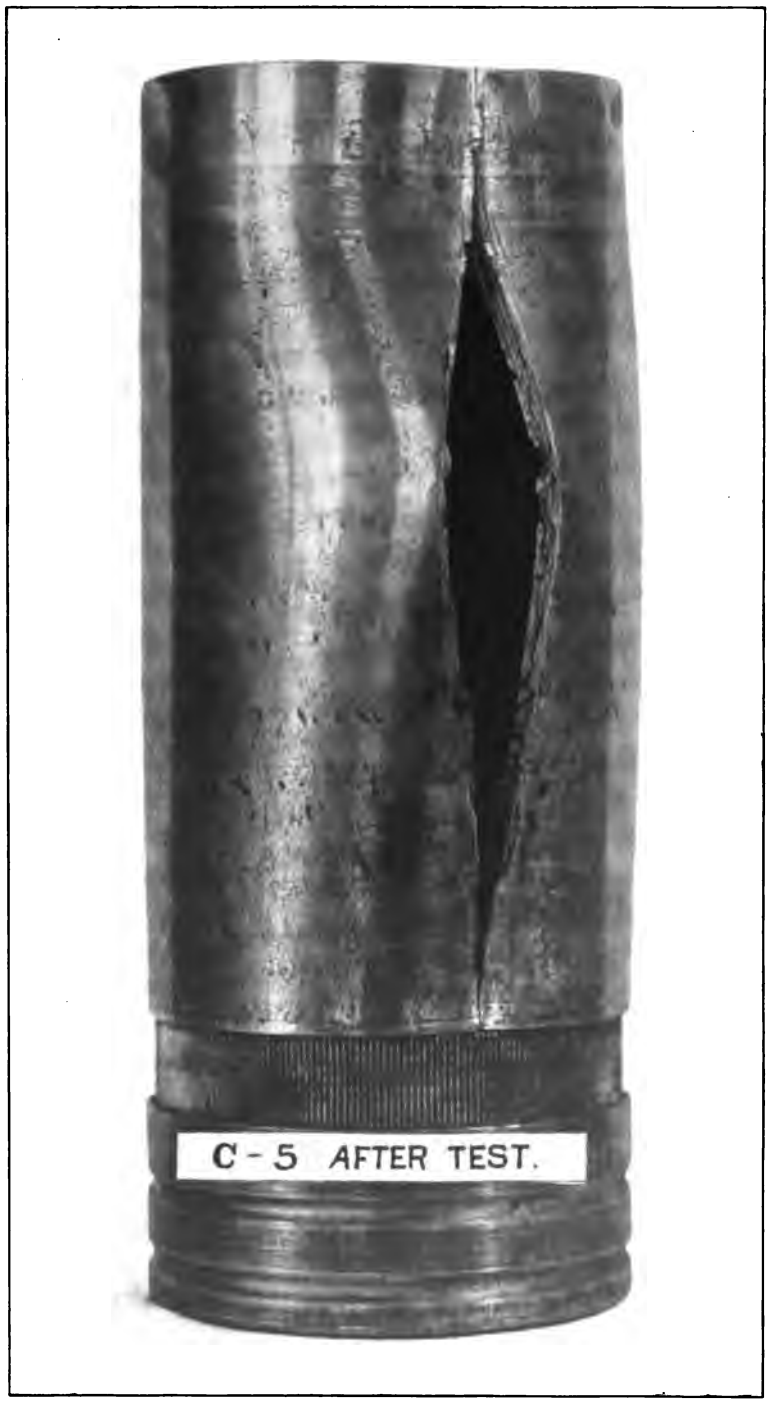
Case etched with iodine.
Short streaks were visible in case before testing.
Outside diameter of case, 2.97 inches.
Inside diameter of case, 2.63 inches.
Length of threaded section at top: Not threaded.
Bored out for a length of 5.53 inches.
Depth inside, 7.04 inches.
Length over all outside, 7.41 inches.
Length from top to top edge of band groove, 5.67 inches.
Case entered testing cylinder 1 inch, leaving 4.53 inches length of reduced thickness of walls exposed to the interior pressure of the test.
Diameter of piston, 2.62 inches.
Sectional area, 5.39 square inches.

Applied loads.			Remarks.
Total pounds on piston.	Interior pressure (pounds per square inch).	Fiber stress on case (pounds per square inch).	
80,000	14,842	114,972	Ultimate strength.

Longitudinal rupture.
Fracture started near the middle of case.
A few internal streaks visible in fracture.
Appearance of fracture, lamellar.



3-INCH SHRAPNEL CASE MADE FROM BAR STOCK. NO. C-5.



3-INCH SHRAPNEL CASE MADE FROM BAR STOCK. NO. C-5.

3-INCH SHRAPNEL CASE MADE FROM BAR STOCK. NO. C-6.

3-INCH SHRAPNEL CASE MADE FROM BAR STOCK. NO. C-6.

NINETEENTH CASE.—3-INCH SHRAPNEL CASE D-1.

Chemical analysis.

C	0.506
Mn	.85
Si	.104
S	.013
P	.018
V	.19

Case etched with iodine.
Streaks were visible in case before testing.
Outside diameter of case, 2.97 inches.
Inside diameter of case, 2.63 inches.
Length of threaded section at top: Not threaded.
Bored out for a length of 5.55 inches.
Depth inside, 7.02 inches.
Length over all outside, 7.42 inches.
Length from top to top edge of band groove, 5.65 inches.
Case entered testing cylinder 1 inch, leaving 4.55 inches length of reduced thickness of walls exposed to the interior pressure of the test.
Diameter of piston, 2.62 inches.
Sectional area, 5.39 square inches.

Applied loads.			Remarks.
Total pounds on piston.	Interior pressure (pounds per square inch).	Fiber stress on case (pounds per square inch).	
84,900	15,751	121,881	Ultimate strength.

Longitudinal rupture.
Fracture started at outside streak near middle of case.
Internal streaks visible in fracture.
Appearance of fracture, fine granular and lamellar.
Several checks developed in different parts of the case during the test.
Case tore around band groove.

TWENTIETH CASE.—3-INCH SHRAPNEL CASE D-2.

(Chemical analysis, see case D-1.)

Case etched with iodine.
Short streaks visible in case before testing.
Outside diameter of case, 2.97 inches.
Inside diameter of case, 2.63 inches.
Length of threaded section at top: Not threaded.
Bored out for a length of, 5.53 inches.
Depth inside, 7.00 inches.
Length over all outside, 7.40 inches.
Length from top to top edge of band groove, 5.65 inches.
Case entered testing cylinder 1 inch, leaving 4.53 inches length of reduced thickness of walls exposed to the interior pressure of the test.
Diameter of piston, 2.62 inches.
Sectional area, 5.39 square inches.

Applied loads.			Remarks.
Total pounds on piston.	Interior pressure (pounds per square inch).	Fiber stress on case (pounds per square inch).	
80,000	14,842	114,972	Ultimate strength.

Longitudinal rupture.
Fracture started a little below the middle of case.
Short streaks visible in fracture.
Appearance of fracture, fine granular and silky.
Small checks developed in different parts of the case during the test.

3-INCH SHRAPNEL CASE MADE FROM BAR STOCK. NO. D-1.

3-INCH SHRAPNEL CASE MADE FROM BAR STOCK. NO. D-1.

3-INCH SHRAPNEL CASE MADE FROM BAR STOCK. NO. D-2.

3-INCH SHRAPNEL CASE MADE FROM BAR STOCK. NO. D-2.

TWENTY-FIRST CASE.—3-INCH SHRAPNEL CASE D-3.

(Chemical analysis, see case D-1.)

Case etched with iodine.
Streaks visible in case before testing.
Outside diameter of case, 2.97 inches.
Inside diameter of case, 2.63 inches.
Length of threaded section at top: Not threaded.
Bored out for a length of 5.52 inches.
Depth inside, 7.02 inches.
Length over all outside, 7.41 inches.
Length from top to top edge of band groove, 5.65 inches.
Case entered testing cylinder 1 inch, leaving 4.52 inches length of reduced thickness of walls exposed to the interior pressure of the test.
Diameter of piston, 2.62 inches.
Sectional area, 5.39 square inches.

Applied loads.			Remarks.
Total pounds on piston.	Interior pressure (pounds per square inch).	Fiber stress on case (pounds per square inch).	
75,600	14,026	108,649	Ultimate strength.

Longitudinal rupture.
Fracture started a little below the middle of case, extending down and partly through the base.
Internal streaks visible in fracture.
Appearance of fracture, fine granular and silky.

TWENTY-SECOND CASE.—3.8-INCH SHRAPNEL CASE A-7.

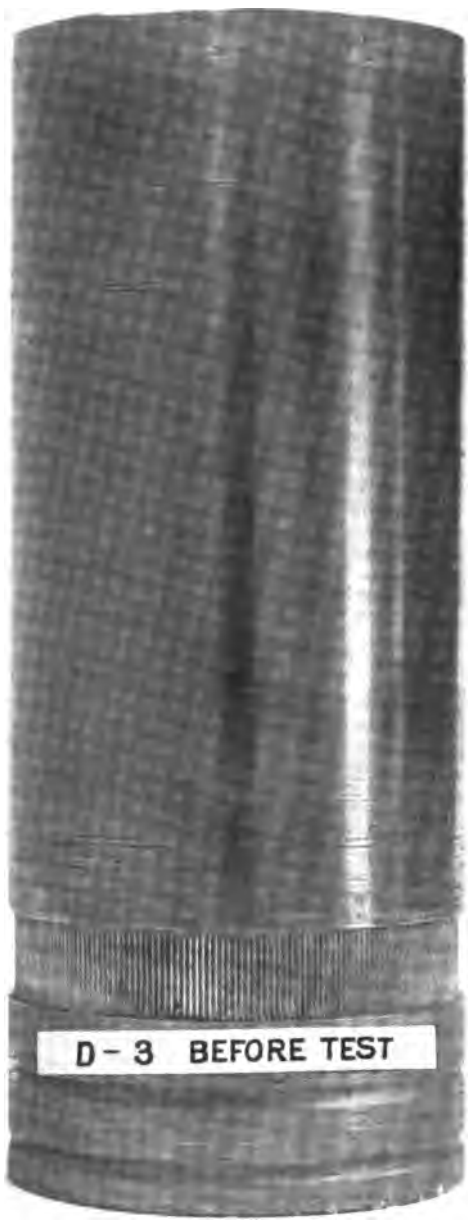
Chemical analysis.

C	0.376
Mn	.71
Si	.069
S	.025
P	.013
Ni	1.22
Cr	.59

Case etched with iodine.
Streaks visible in case before testing.
Outside diameter of case, 3.77 inches.
Inside diameter of case, 3.37 inches.
Length of threaded section at top: Not threaded.
Bored out for a length of 6.95 inches.
Depth inside, 8.85 inches.
Length over all outside, 9.37 inches.
Length from top to top edge of band groove, 7.17 inches.
Case entered testing cylinder 1½ inches, leaving 5.45 inches length of reduced thickness of walls exposed to the interior pressure of the test.
Diameter of piston, 3.25 inches.
Sectional area, 8.29 square inches.

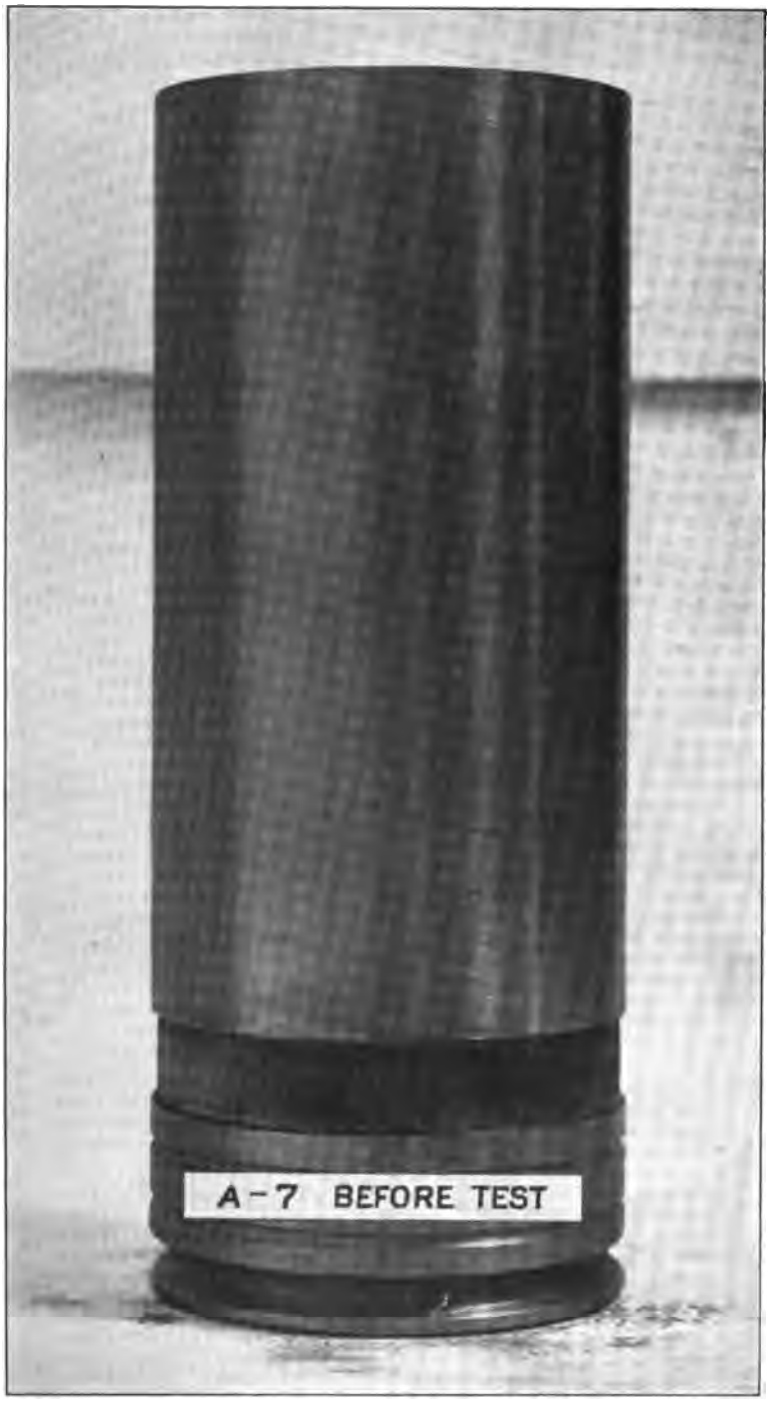
Applied loads.			Remarks.
Total pounds on piston.	Interior pressure (pounds per square inch).	Fiber stress on case (pounds per square inch).	
115,600	13,940	117,400	Ultimate strength.

Longitudinal rupture.
Fracture started at a lamellar spot near the middle of case.
A few internal streaks visible in fracture.
Appearance of fracture, fine granular.



3-INCH SHRAPNEL CASE MADE FROM BAR STOCK. NO. D-3.

3-INCH SHRAPNEL CASE MADE FROM BAR STOCK. NO. D-3.



3.8-INCH SHRAPNEL CASE MADE FROM BAR STOCK. NO. A-7.

3.8-INCH SHRAPNEL CASE MADE FROM BAR STOCK. NO. A-7.

TWENTY-THIRD CASE.—3.8-INCH SHRAPNEL CASE A-8.

(Chemical analysis, see Case A-7.)

Case etched with iodine.
Streaks visible in case before testing.
Outside diameter of case, 3.77 inches.
Inside diameter of case, 3.37 inches.
Length of threaded section at top: Not threaded.
Bored out for a length of 6.95 inches.
Depth inside, 8.85 inches.
Length over all outside, 9.37 inches.
Length from top to top edge of band groove, 7.17 inches.
Case entered testing cylinder 1½ inches, leaving 5.45 inches length of reduced thickness of walls exposed to the interior pressure of the test.
Diameter of piston, 3.25 inches.
Sectional area, 8.29 square inches.

Applied loads.			Remarks.
Total pounds on piston.	Interior pressure (pounds per square inch).	Fiber stress on case (pounds per square inch).	
111,500	13,450	113,240	Ultimate strength.

Longitudinal rupture.
Fracture started at a lamellar spot near the top of case.
Numerous internal streaks visible in fracture.
Appearance of fracture, fine granular.

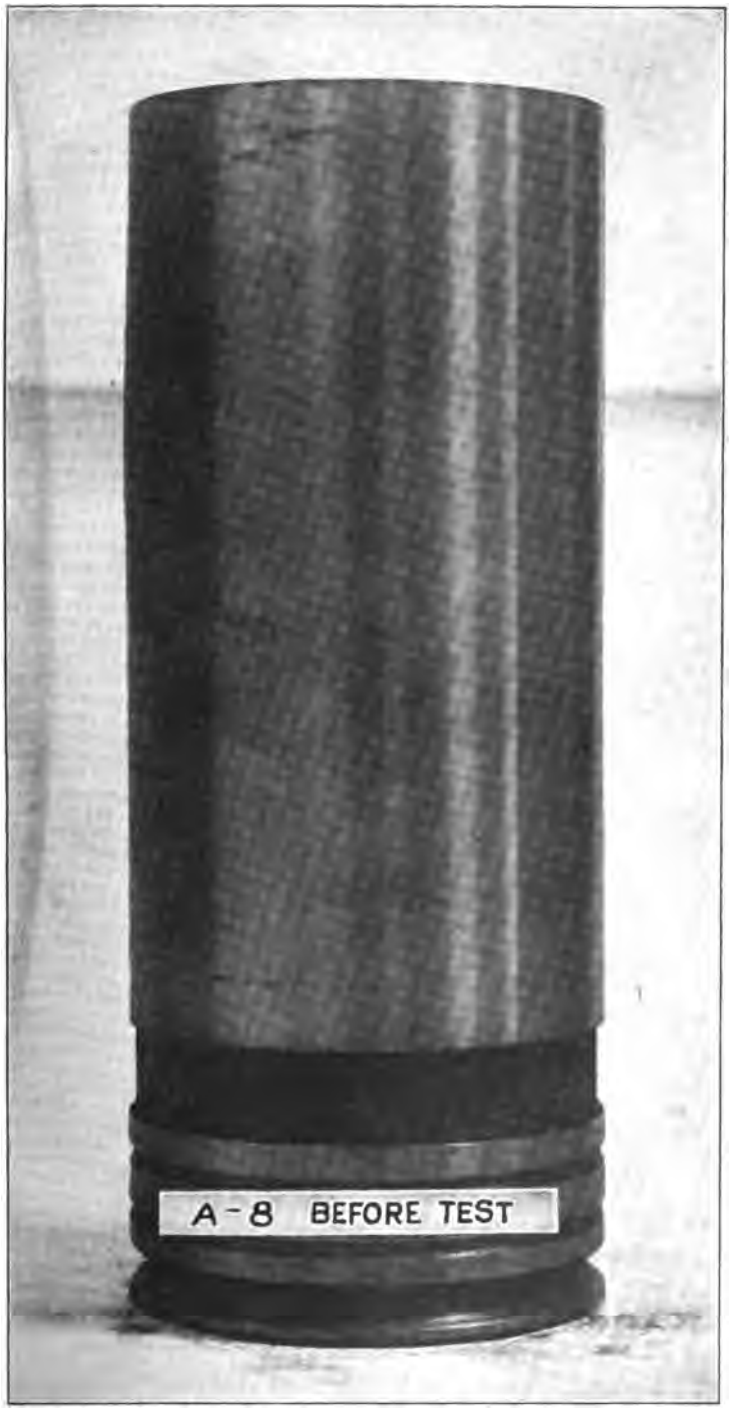
TWENTY-FOURTH CASE.—3.8-INCH SHRAPNEL CASE A-9.

(Chemical analysis, see Case A-7.)

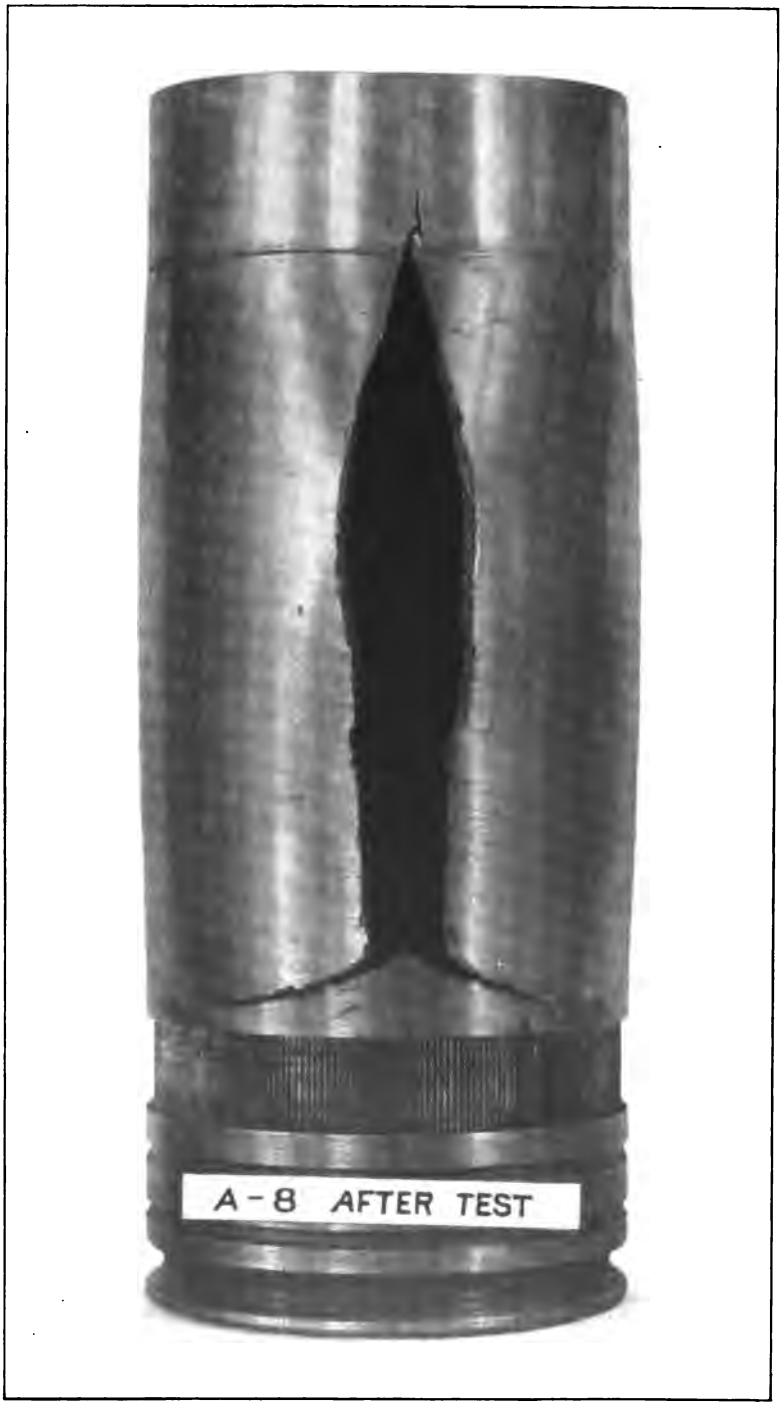
Case etched with iodine.
Streaks visible in case before testing.
Outside diameter of case, 3.77 inches.
Inside diameter of case, 3.37 inches.
Length of threaded section at top: Not threaded.
Bored out for a length of 6.95 inches.
Depth inside, 8.84 inches.
Length over all outside, 9.37 inches.
Length from top to top edge of band groove, 7.17 inches.
Case entered testing cylinder 1½ inches, leaving 5.45 inches length of reduced thickness of walls exposed to the interior pressure of the test.
Diameter of piston, 3.25 inches.
Sectional area, 8.29 square inches.

Applied loads.			Remarks.
Total pounds on piston.	Interior pressure (pounds per square inch).	Fiber stress on case (pounds per square inch).	
122,200	14,740	124,100	Ultimate strength.

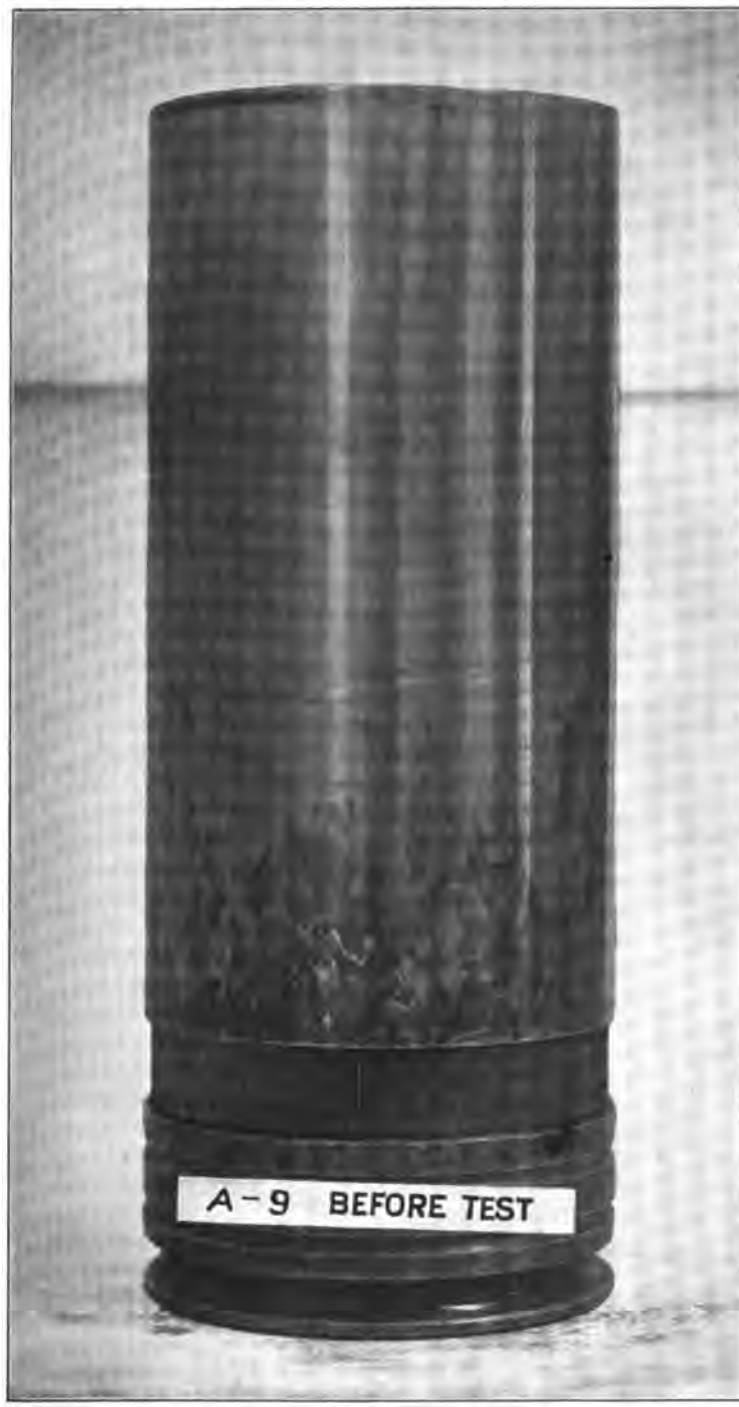
Longitudinal rupture.
Fracture started at a lamellar streak near the top of case.
Numerous internal streaks visible in fracture.
Appearance of fracture, lamellar and silky.



3.8-INCH SHRAPNEL CASE MADE FROM BAR STOCK. NO. A-8.



3.8-INCH SHRAPNEL CASE MADE FROM BAR STOCK. NO. A-8.



3.8-INCH SHRAPNEL CASE MADE FROM BAR STOCK. NO. A-9.

3.8-INCH SHRAPNEL CASE MADE FROM BAR STOCK. NO. A-9.

TWENTY-FIFTH CASE.—4.7-INCH SHRAPNEL CASE E-1.

Chemical analysis.

C	0.618
Mn	.70
Si	.152
S	.020
P	.060
Ni	3.50

Case etched with iodine.
No streaks visible in case before testing.
Outside diameter of case, 4.68 inches.
Inside diameter of case, 4.28 inches.
Length of threaded section at top: Not threaded.
Bored out for a length of 8.66 inches.
Depth inside, 11.14 inches.
Length over all outside, 11.77 inches.
Length from top to top edge of band groove, 9.00 inches.
Case entered testing cylinder 1½ inches, leaving 7.16 inches length of reduced thickness of walls exposed to the interior pressure of the test.
Diameter of piston, 5.00 inches.
Sectional area, 19.63 square inches.

Applied loads.			Remarks.
Total pounds on piston.	Interior pressure (pounds per square inch).	Fiber stress on case (pounds per square inch).	
168,200	8,580	92,100	Ultimate strength.

Longitudinal rupture.
Fracture started at a silky spot near the middle of case, extending down through the base and up on the opposite side.
Several internal streaks visible in fracture.
Three fragments were detached from case, one 7 inches long by 2½ inches wide, and two 1⅝ inches long by about ⅜ inch wide.
Appearance of fracture, medium coarse granular.

TWENTY-SIXTH CASE.—4.7-INCH SHRAPNEL CASE E-2.

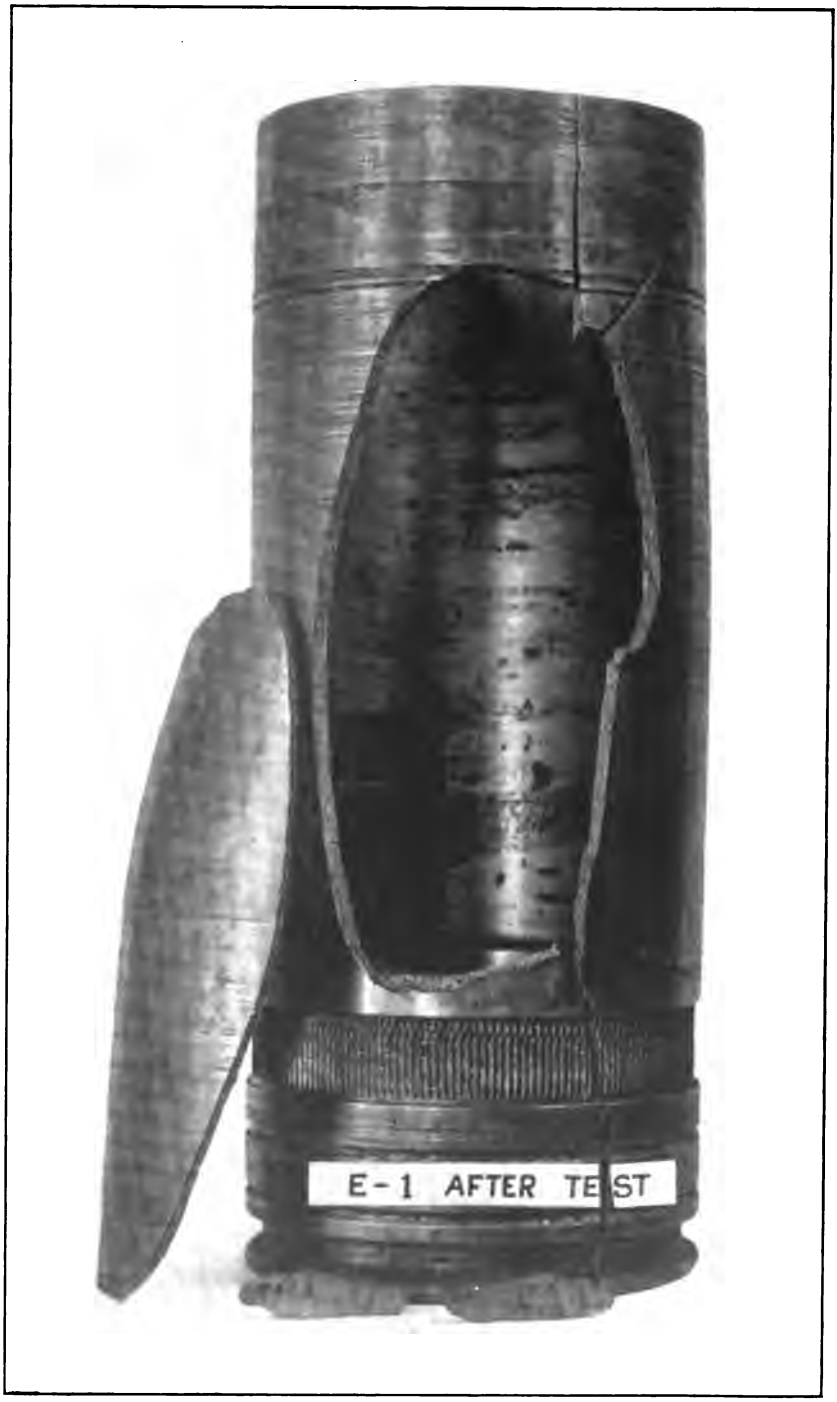
(Chemical analysis, see Case E-1.)

Case etched with iodine.
Outside diameter of case, 4.68 inches.
Inside diameter of case, 4.28 inches.
Length of threaded section at top: Not threaded.
Bored out for a length of 8.65 inches.
Depth inside, 11.14 inches.
Length over all outside, 11.75 inches.
Length from top to top edge of band groove, 9.00 inches.
Case entered testing cylinder 1½ inches, leaving 7.15 inches length of reduced thickness of walls exposed to the interior pressure of the test.
Diameter of piston, 5.00 inches.
Sectional area, 19.63 square inches.

Applied loads.			Remarks.
Total pounds on piston.	Interior pressure (pounds per square inch).	Fiber stress on case (pounds per square inch).	
162,000	8,250	88,500	Ultimate strength.

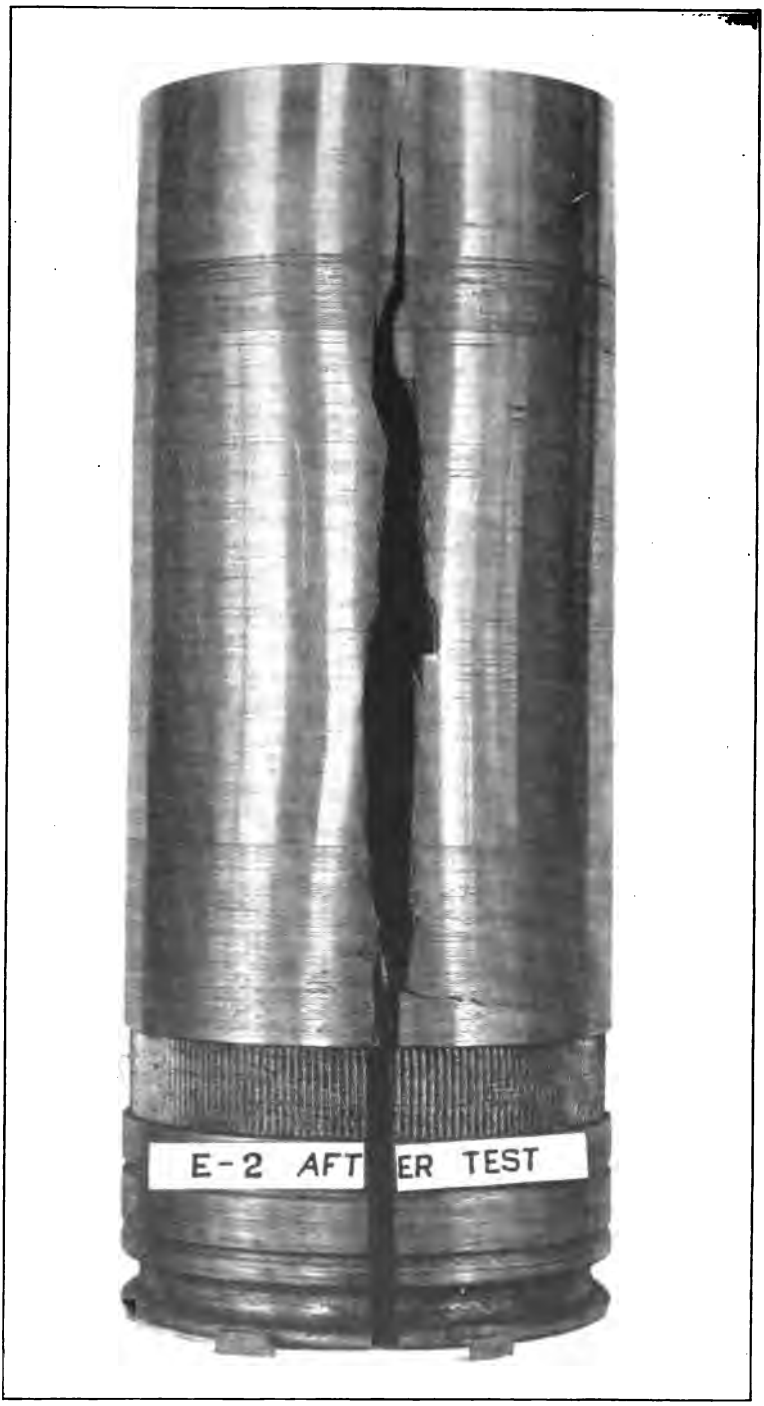
Longitudinal rupture.
Fracture started at a small lamellar spot near the middle of case, extending down through the base and up on the opposite side.
Numerous internal streaks visible in fracture, also in base.
Several checks near fracture developed in case during the test.
Two small fragments ½ inch long by about ⅛ inch wide were detached from case.
Appearance of fracture, medium coarse granular and lamellar.

4.7-INCH SHRAPNEL CASE MADE FROM BAR STOCK. NO. E-1.



4.7-INCH SHRAPNEL CASE MADE FROM BAR STOCK. NO. E-1.

4.7-INCH SHRAPNEL CASE MADE FROM BAR STOCK. NO. E-2.



4.7-INCH SHRAPNEL CASE MADE FROM BAR STOCK. NO. E-2.

TWENTY-SEVENTH CASE.—4.7-INCH SHRAPNEL CASE E-3.

(Chemical analysis, see Case E-1.)

Case etched with iodine.
No streaks visible in case before testing.
Outside diameter of case, 4.68 inches.
Inside diameter of case, 4.28 inches.
Length of threaded section at top: Not threaded.
Bored out for a length of 8.65 inches.
Depth inside, 11.11 inches.
Length over all outside, 11.75 inches.
Length from top to top edge of band groove, 9 inches.
Case entered testing cylinder 1½ inches, leaving 7.15 inches length of reduced thickness of walls exposed to the interior pressure of the test.
Diameter of piston, 5.00 inches.
Sectional area, 19.63 square inches.

Applied loads.			Remarks.
Total pounds on piston.	Interior pressure (pounds per square inch).	Fiber stress on case (pounds per square inch).	
218,300	11,120	119,022	Ultimate strength.

Longitudinal rupture.
Fracture started near the middle of case.
Numerous internal streaks visible in fracture.
Appearance of fracture, fine granular.

HYDROSTATIC, TENSILE, HARDNESS, AND CHARPY IMPACT TESTS OF SIX 3-INCH SHRAPNEL CASES MADE FROM HAMMERED BAR STOCK.

HYDROSTATIC TEST.

Six shrapnel cases and two bars 3.10 inches diameter and 12 inches long were tested.

Cases marked A–1, A–2, B–1, B–2, C–1, and C–2.

FIRST CASE.—3-INCH SHRAPNEL CASE A–1.

Case etched with iodine.

No streaks or seams visible before test.

Outside diameter of case, 2.97 inches.

Inside diameter of case, 2.63 inches.

Bored out for a length of 5.50 inches.

Depth inside, 6.98 inches.

Length over all outside, 7.40 inches.

Case entered testing cylinder 1 inch, leaving 4.50 inches length of reduced thickness of walls exposed to the interior pressure of the test.

Diameter of piston, 2.62 inches.

Sectional area, 5.39 square inches.

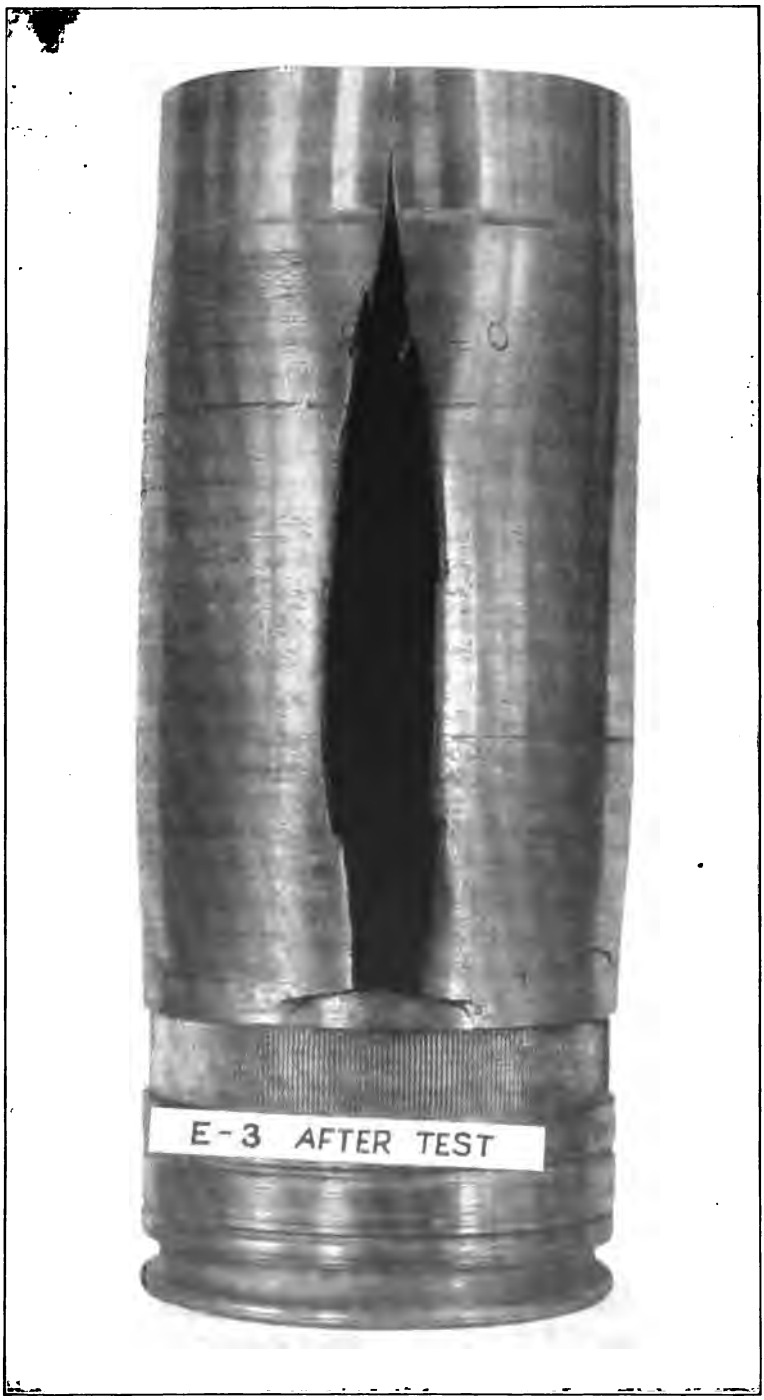
Applied loads.			Remarks.
Total pounds on piston.	Interior pressure (pounds per square inch).	Fiber stress on case (pounds per square inch).	
78,800	14,610	113,100	Ultimate strength.

Longitudinal rupture. Fracture started near the top of case. No streaks or seams visible.

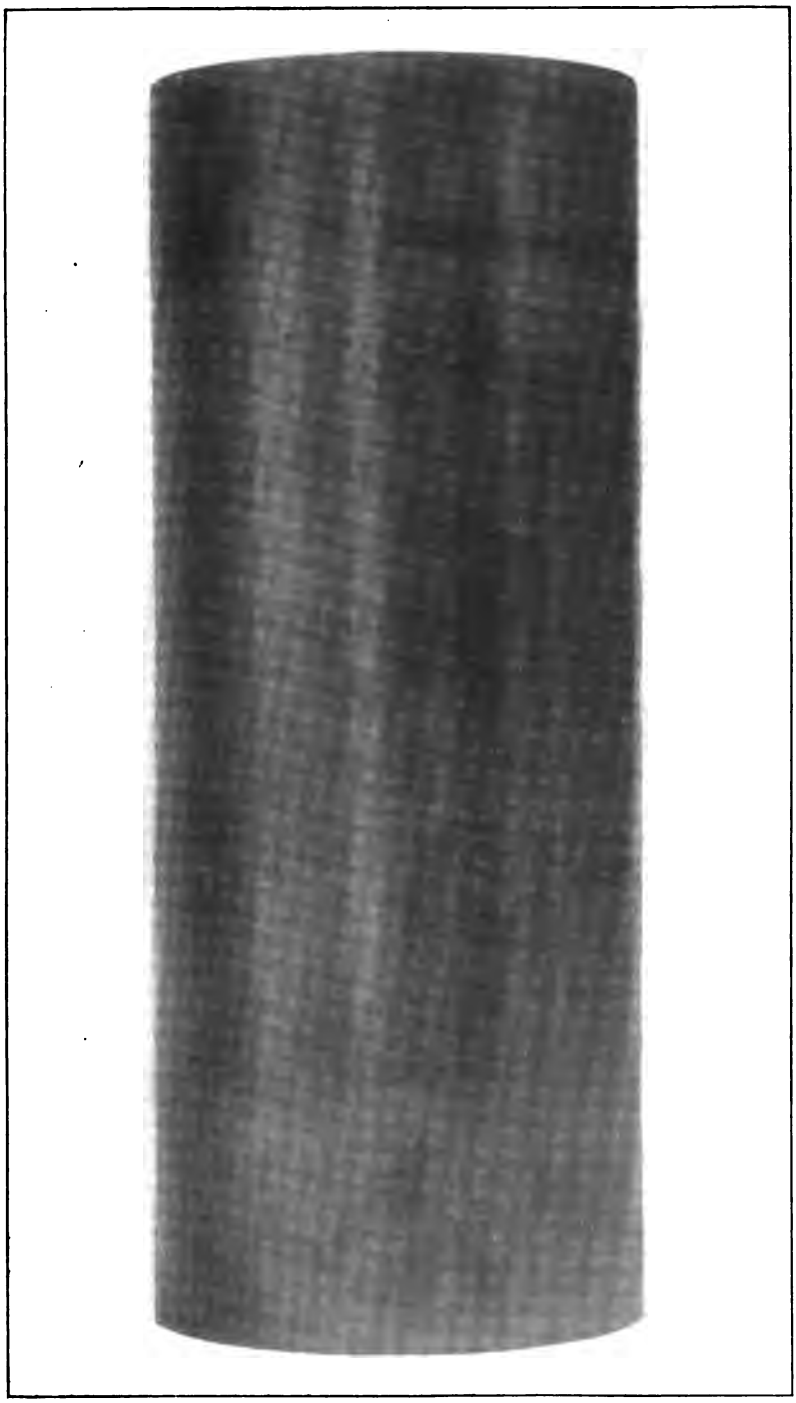
Appearance of fracture, silky and lamellar. Small checks developed in different parts of the case during the test.

This case made from heat-treated hammered bar stock.

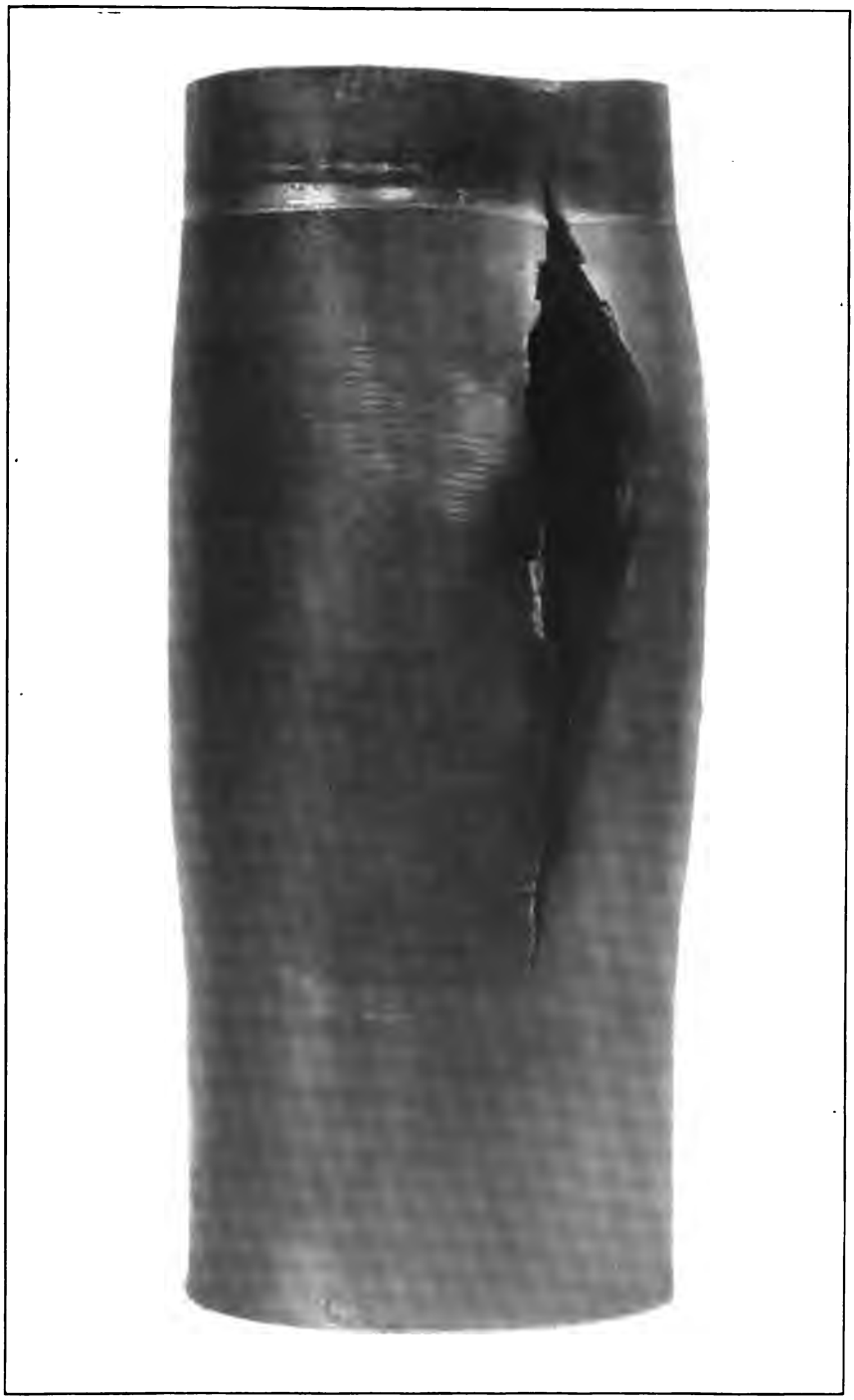
4.7-INCH SHRAPNEL CASE MADE FROM BAR STOCK. NO. E-3.



4.7-INCH SHRAPNEL CASE MADE FROM BAR STOCK. NO. E-3.



3-INCH SHRAPNEL CASE MADE FROM HEAT-TREATED, HAMMERED BAR STOCK. CASE MARKED A-1. BEFORE TEST.



3-INCH SHRAPNEL CASE MARKED A-1. AFTER TEST.

SECOND CASE.—3-INCH SHRAPNEL CASE A-2.

Case etched with iodine.
No streaks or seams visible before test.
Outside diameter of case, 2.97 inches.
Inside diameter of case, 2.63 inches.
Bored out for a length of 5.50 inches.
Depth inside, 6.98 inches.
Length over all outside, 7.40 inches.
Case entered testing cylinder 1 inch, leaving 4.50 inches length of reduced thickness of walls exposed to the interior pressure of the test.
Diameter of piston, 2.62 inches.
Sectional area, 5.39 square inches.

Applied loads.			Remarks.
Total pounds on piston.	Interior pressure (pounds per square inch).	Fiber stress on case (pounds per square inch).	
73,600	13,650	105,600	Ultimate strength.

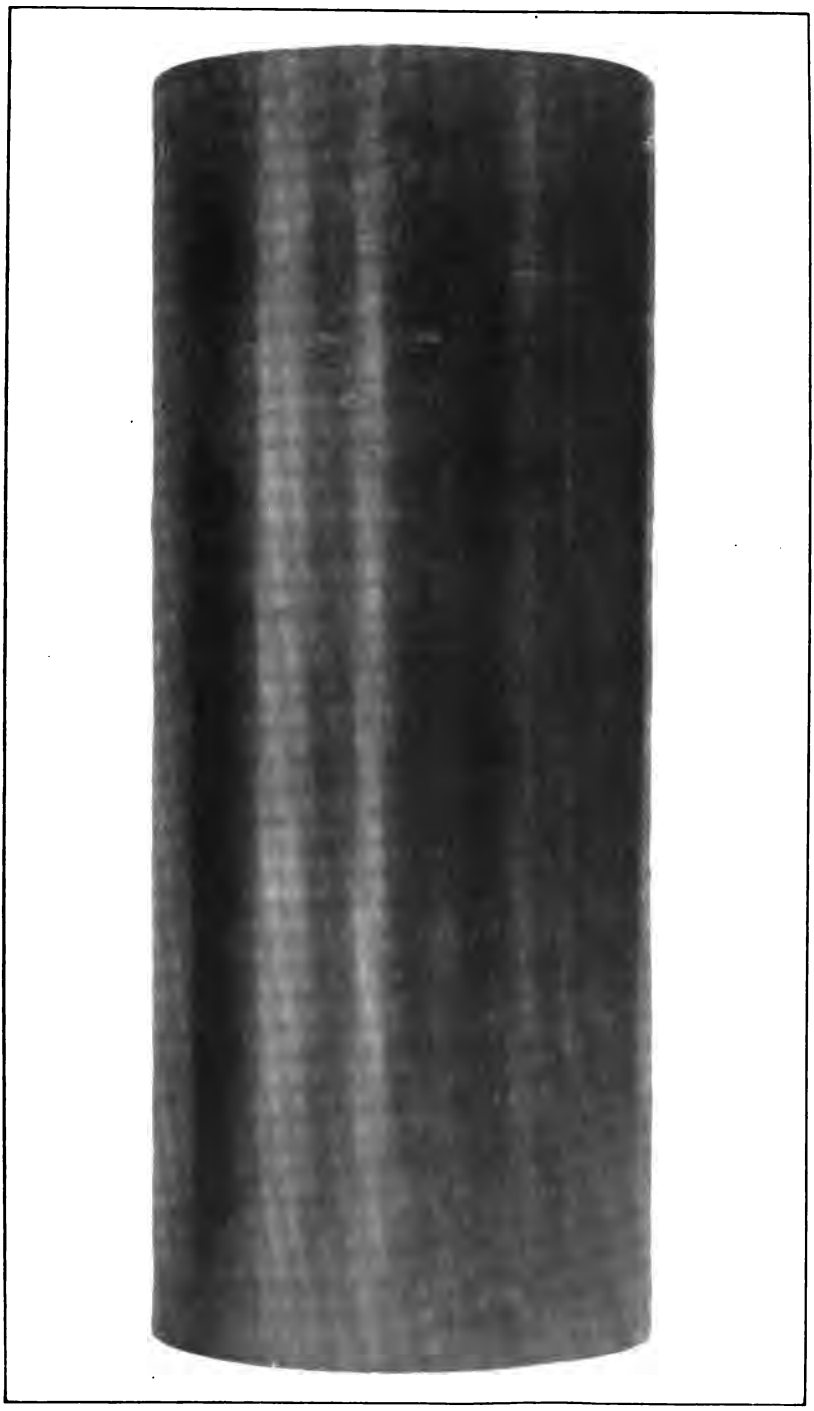
Longitudinal rupture.
Fracture started near the middle of case.
No streaks or seams visible.
Fracture appeared silky.
Small checks developed in different parts of the case.
This case made from heat treated hammered bar stock, similar to case A-1.

THIRD CASE.—3-INCH SHRAPNEL CASE B-1.

Case etched with iodine.
No streaks or seams visible before test.
Outside diameter of case, 2.97 inches.
Inside diameter of case, 2.63 inches.
Bored out for a length of 5.50 inches.
Depth inside, 6.98 inches.
Length over all outside, 7.40 inches.
Case entered testing cylinder 1 inch, leaving 4.50 inches length of reduced thickness of walls exposed to the interior pressure of the test.
Diameter of piston, 2.62 inches.
Sectional area, 5.39 square inches.

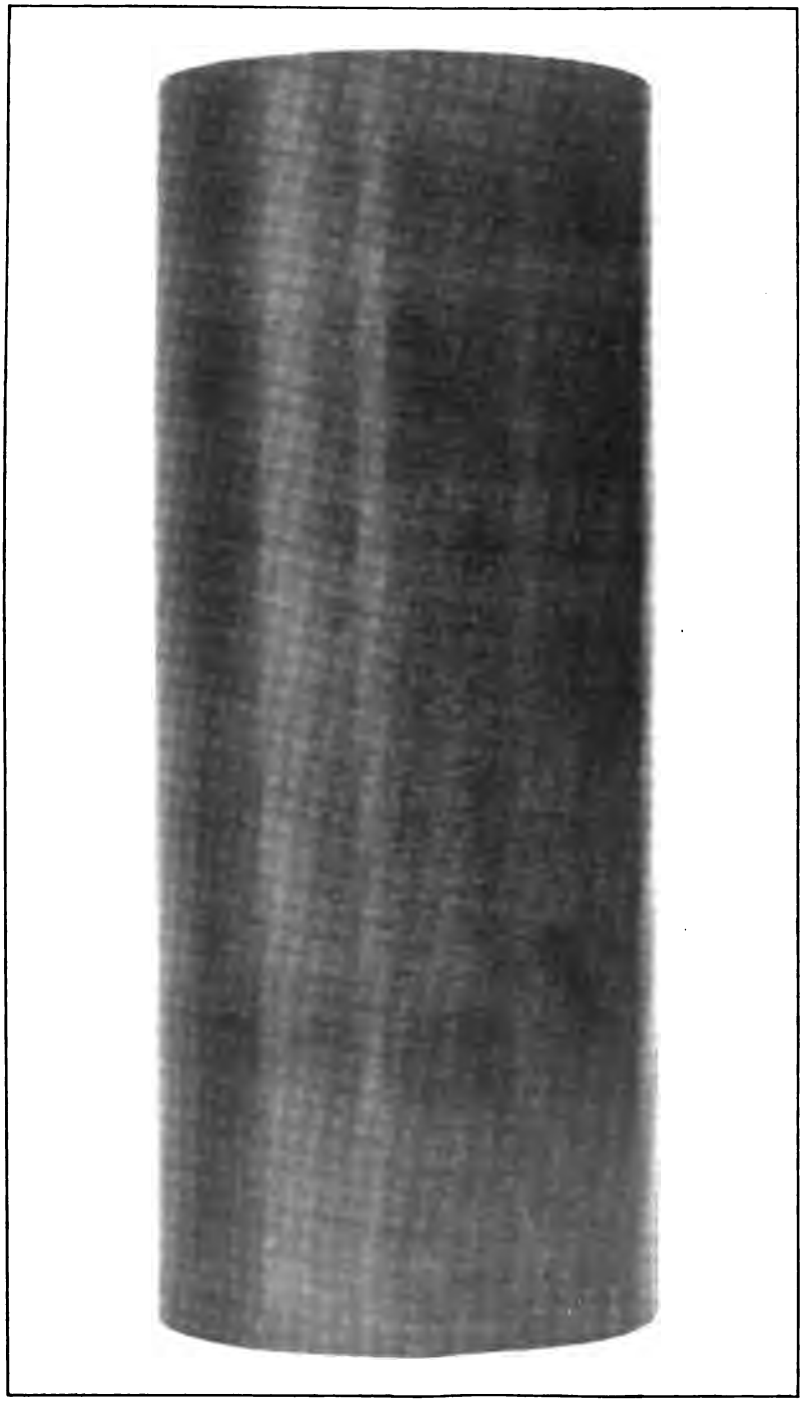
Applied loads.			Remarks.
Total pounds on piston.	Interior pressure (pounds per square inch).	Fiber stress on case (pounds per square inch).	
85,200	15,800	122,200	Ultimate strength.

Longitudinal rupture.
Fracture started near the top of case.
No streaks or seams visible.
The fracture appeared silky and lamellar.
This case made from heat-treated hammered bar stock.

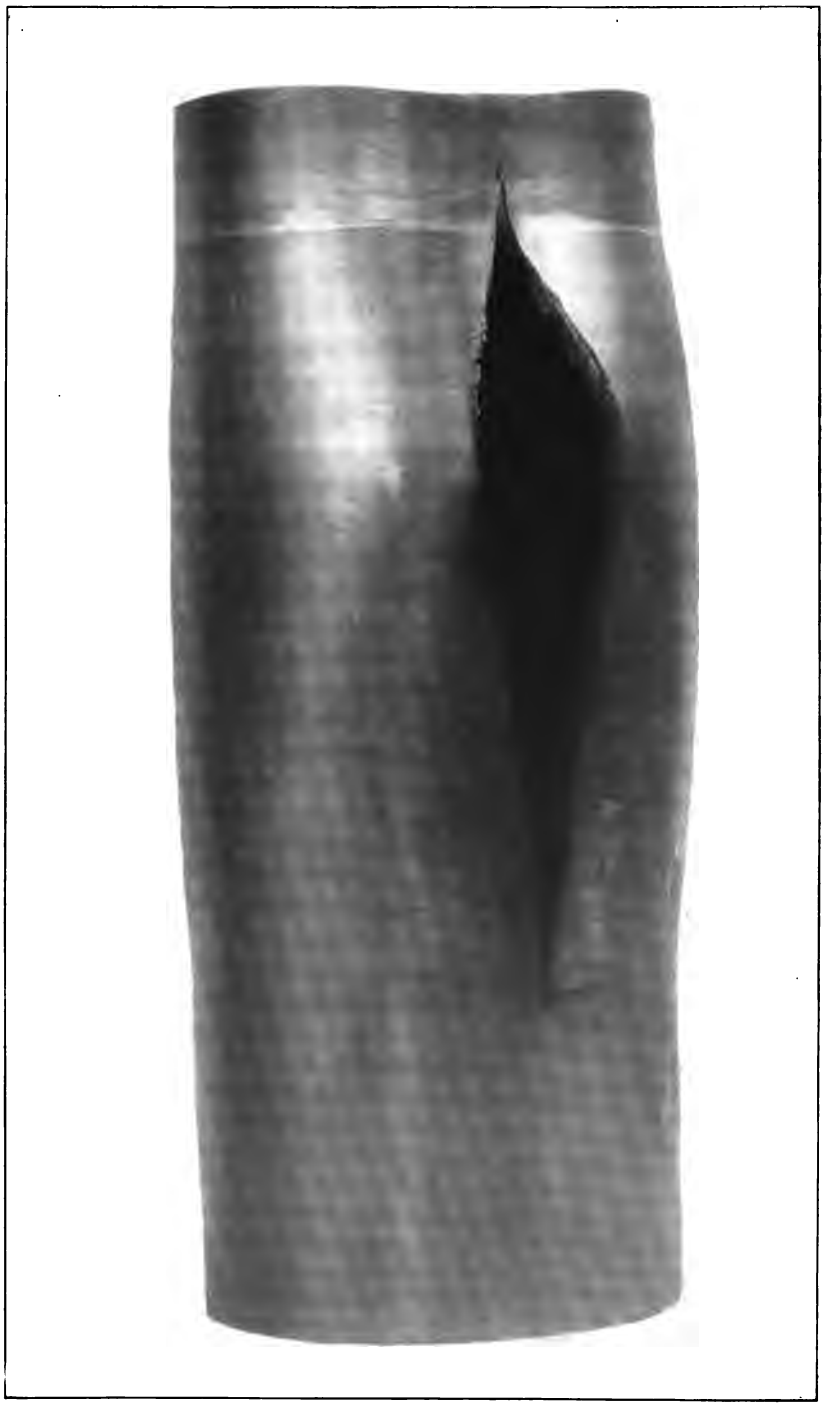


3-INCH SHRAPNEL CASE MARKED A-2. BEFORE TEST. CASE MADE FROM HEAT-TREATED HAMMERED BAR STOCK.

3-INCH SHRAPNEL CASE MARKED A–2. AFTER TEST.



3-INCH SHRAPNEL CASE MARKED B–1. BEFORE TEST. CASE MADE FROM HEAT-TREATED HAMMERED BAR STOCK.



3-INCH SHRAPNEL CASE MARKED B-1. AFTER TEST.

FOURTH CASE.—3-INCH SHRAPNEL CASE B-2.

Case etched with iodine.
No streaks or seams visible before test.
Outside diameter of case, 2.97 inches.
Inside diameter of case, 2.63 inches.
Bored out for a length of 5.50 inches.
Depth inside, 6.98 inches.
Length over all outside, 7.40 inches.
Case entered testing cylinder 1 inch, leaving 4.50 inches length of reduced thickness of walls exposed to the interior pressure of the test.
Diameter of piston, 2.62 inches.
Sectional area, 5.39 square inches.

Applied loads.			Remarks.
Total pounds on piston.	Interior pressure (pounds per square inch).	Fiber stress on case (pounds per square inch).	
75,600	14,020	108,500	Ultimate strength.

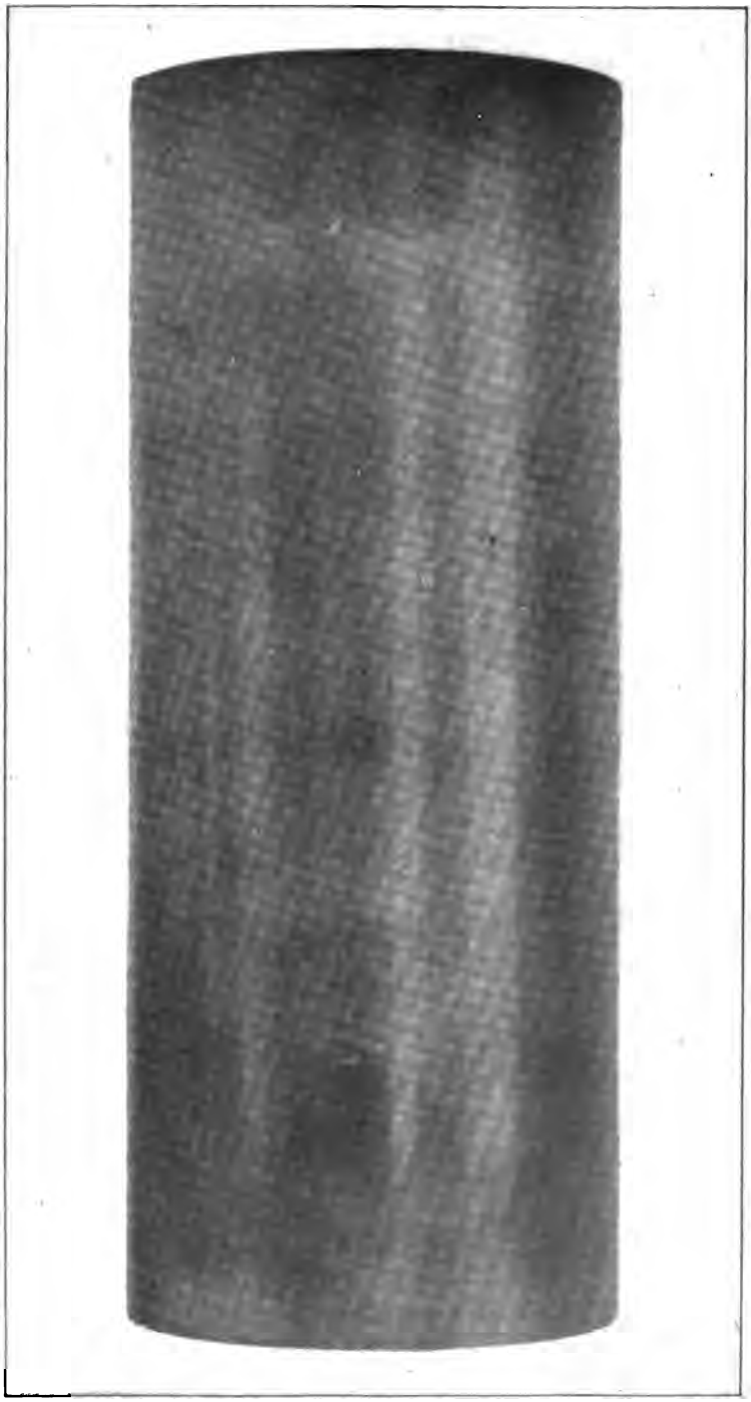
Longitudinal rupture.
Fracture started at a bright streak in the wall of the case near the top.
The fracture appeared silky and lamellar.
This case made from heat treated hammered bar stock, similar to case B-1.

FIFTH CASE.—3-INCH SHRAPNEL CASE C-1.

Case etched with iodine.
No streaks or seams visible before test.
Outside diameter of case, 2.97 inches.
Inside diameter of case, 2.63 inches.
Bored out for a length of 5.50 inches.
Depth inside, 6.98 inches.
Length over all outside, 7.40 inches.
Case entered testing cylinder 1 inch, leaving 4.50 inches length of reduced thickness of walls exposed to the interior pressure of the test.
Diameter of piston, 2.62 inches.
Sectional area, 5.39 square inches.

Applied loads.			Remarks.
Total pounds on piston.	Interior pressure (pounds per square inch).	Fiber stress on case (pounds per square inch).	
82,800	15,360	118,800	Ultimate strength.

Longitudinal rupture.
Fracture started near the top of case.
No streaks or seams visible.
Fracture appeared silky and lamellar.
Small checks developed in different parts of the case during the test.
This case made from hammered bar stock. Case heat treated after rough machining.



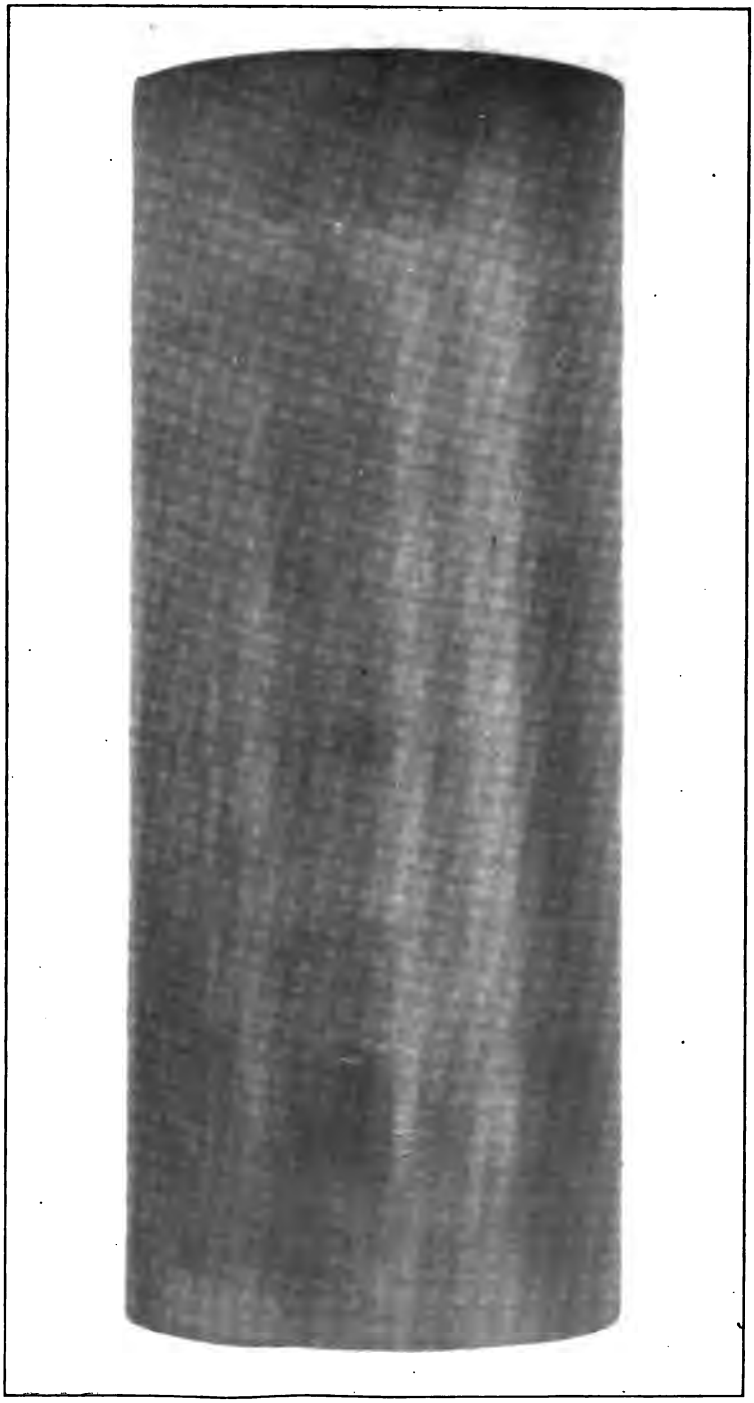
3-INCH SHRAPNEL CASE MARKED B–2. BEFORE TEST. CASE MADE FROM HEAT-TREATED HAMMERED BAR STOCK.

FIFTH CASE.—3-INCH SHRAPNEL CASE C-1.

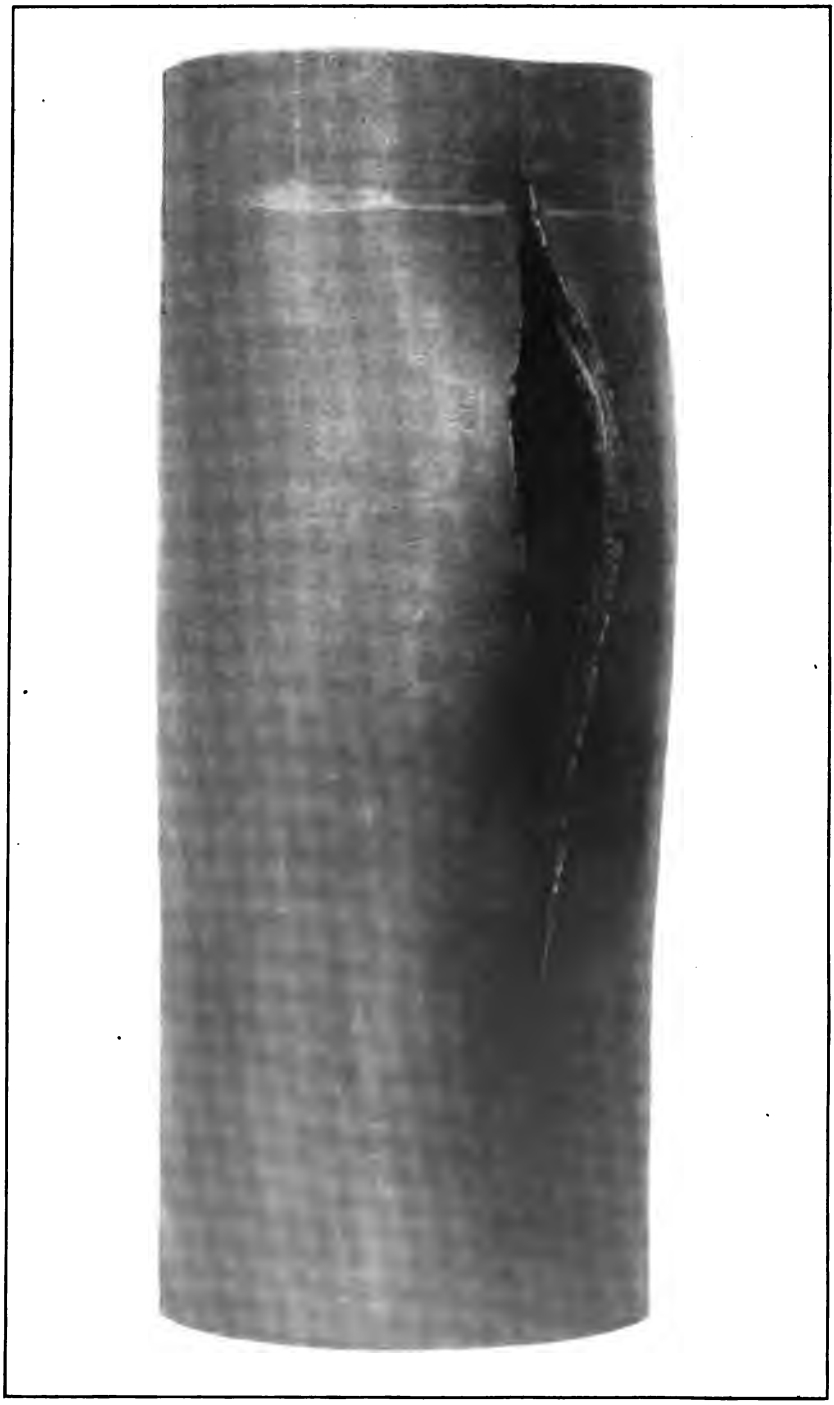
Case etched with iodine.
No streaks or seams visible before test.
Outside diameter of case, 2.97 inches.
Inside diameter of case, 2.63 inches.
Bored out for a length of 5.50 inches.
Depth inside, 6.98 inches.
Length over all outside, 7.40 inches.
Case entered testing cylinder 1 inch, leaving 4.50 inches length of reduced thickness of walls exposed to the interior pressure of the test.
Diameter of piston, 2.62 inches.
Sectional area, 5.39 square inches.

Applied loads.			Remarks.
Total pounds on piston.	Interior pressure (pounds per square inch).	Fiber stress on case (pounds per square inch).	
82,800	15,360	118,800	Ultimate strength.

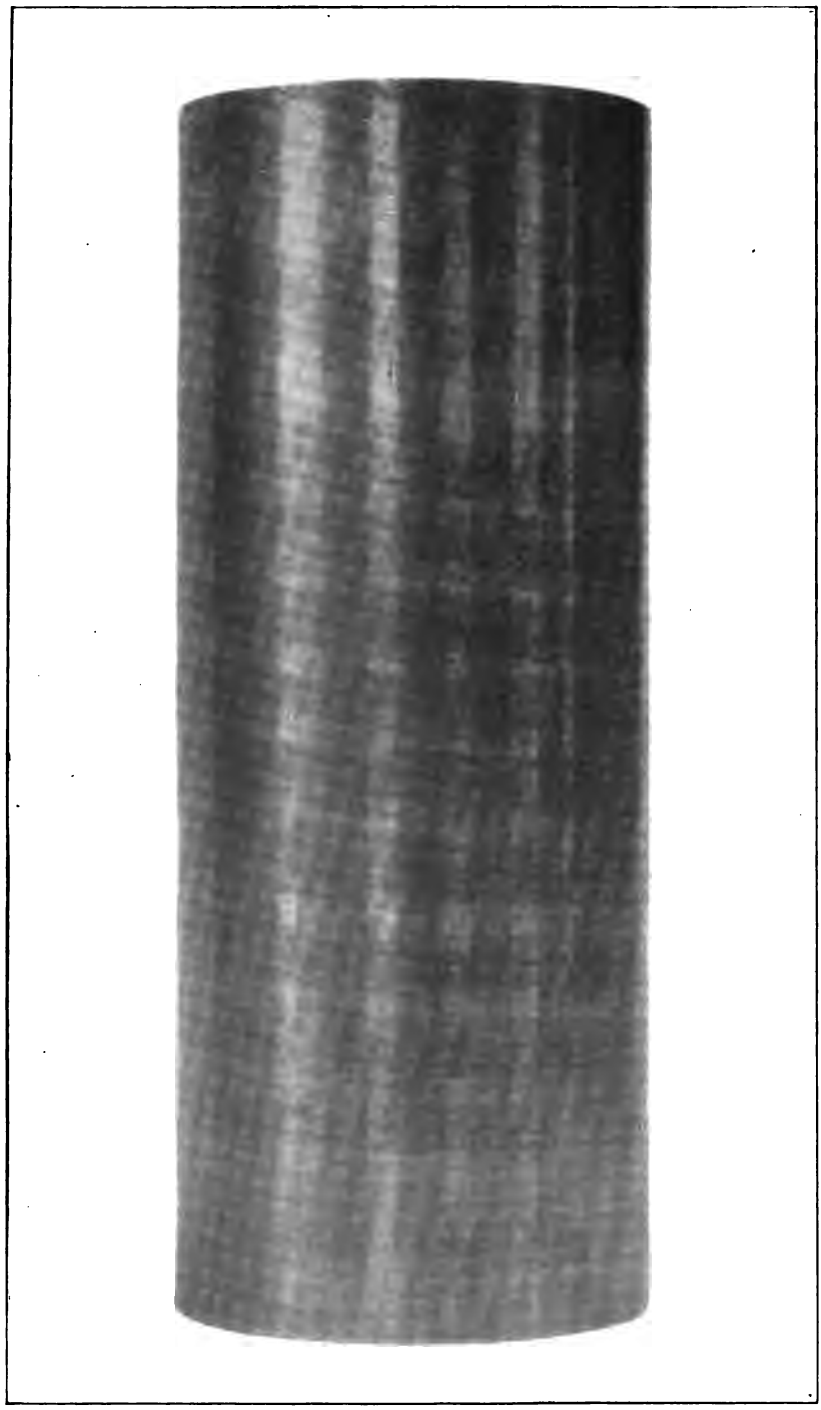
Longitudinal rupture.
Fracture started near the top of case.
No streaks or seams visible.
Fracture appeared silky and lamellar.
Small checks developed in different parts of the case during the test.
This case made from hammered bar stock. Case heat treated after rough machining.



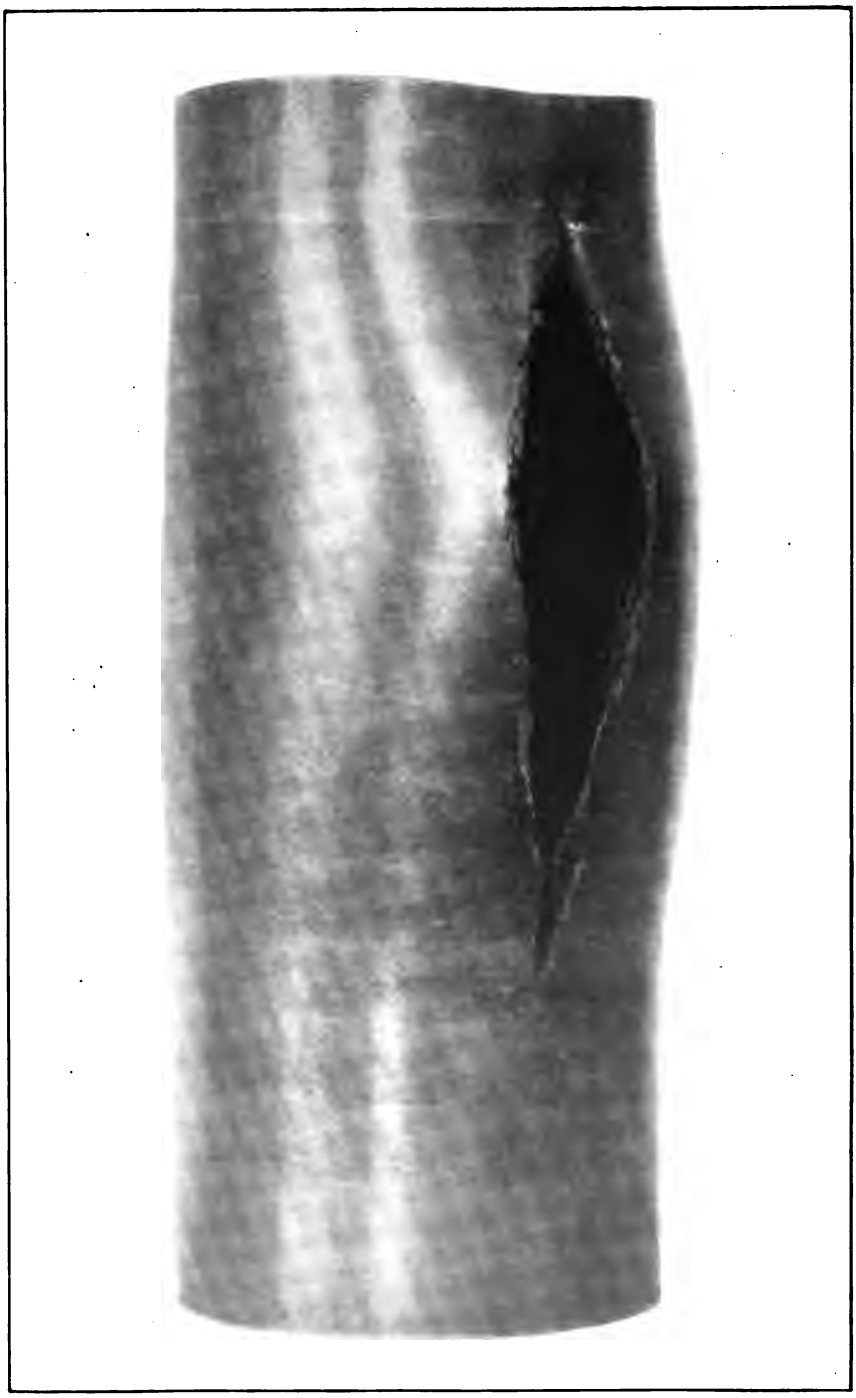
3-INCH SHRAPNEL CASE MARKED B–2. BEFORE TEST. CASE MADE FROM HEAT-TREATED HAMMERED BAR STOCK.



3-INCH SHRAPNEL CASE MARKED B–2. AFTER TEST.



3-INCH SHRAPNEL CASE MARKED C–1. BEFORE TEST. CASE MADE FROM HAMMERED BAR STOCK. HEAT TREATED AFTER ROUGH MACHINING.



3-INCH SHRAPNEL CASE MARKED C–1. AFTER TEST.

SIXTH CASE.—3-INCH SHRAPNEL CASE C-2.

Case etched with iodine.
No streaks or seams visible before test.
Outside diameter of case, 2.97 inches.
Inside diameter of case, 2.63 inches.
Bored out for a length of 5.50 inches.
Depth inside, 7.00 inches.
Length over all outside, 7.40 inches.
Case entered testing cylinder 1 inch, leaving 4.50 inches length of reduced thickness of walls exposed to the interior pressure of the test.
Diameter of piston, 2.62 inches.
Sectional area, 5.39 square inches.

Applied loads.			Remarks.
Total pounds on piston.	Interior pressure (pounds per square inch).	Fiber stress on case (pounds per square inch).	
86,500	16,040	124,000	Ultimate strength.

Longitudinal rupture.
Fracture started near the middle of case.
No streaks or seams visible.
Fracture appeared silky and lamellar.
Small checks developed in different parts of the case during the test.
This case made from hammered bar stock. Case heat treated after rough machining similarly to case C-1.

TENSILE TESTS OF STOCK FOR CASES.

Marks.	Yield point (pounds per square inch).	Elastic limit* (pounds per square inch).	Elongation (per cent).	Contraction (per cent).	Appearance of fracture.
A L.....	.....	116,500	33.0	54.6	Fine silky.
A L.....	75,000	117,000	33.0	54.6	Fine silky. Perfect cup and cone.
A T.....	67,500	112,500	13.0	20.5	Laminated.
A T.....	62,500	113,000	13.0	20.5	Laminated oblique.
B L.....	103,000	142,000	22.0	30.7	Fine silky.
B L.....	101,500	140,500	27.0	37.2	Do.
B T.....	100,000	140,000	11.0	5.7	Laminated. Broke at gage mark.
B T.....	100,000	138,000	11.0	5.7	Laminated.

* Yield point not well defined.

BRINELL HARDNESS NUMBERS.

Marks.....	AL.	AL.	AT.	AT.	BL.	BL.	BT.	BT.
Hardness.....	235	241	241	235	286	277	277	286

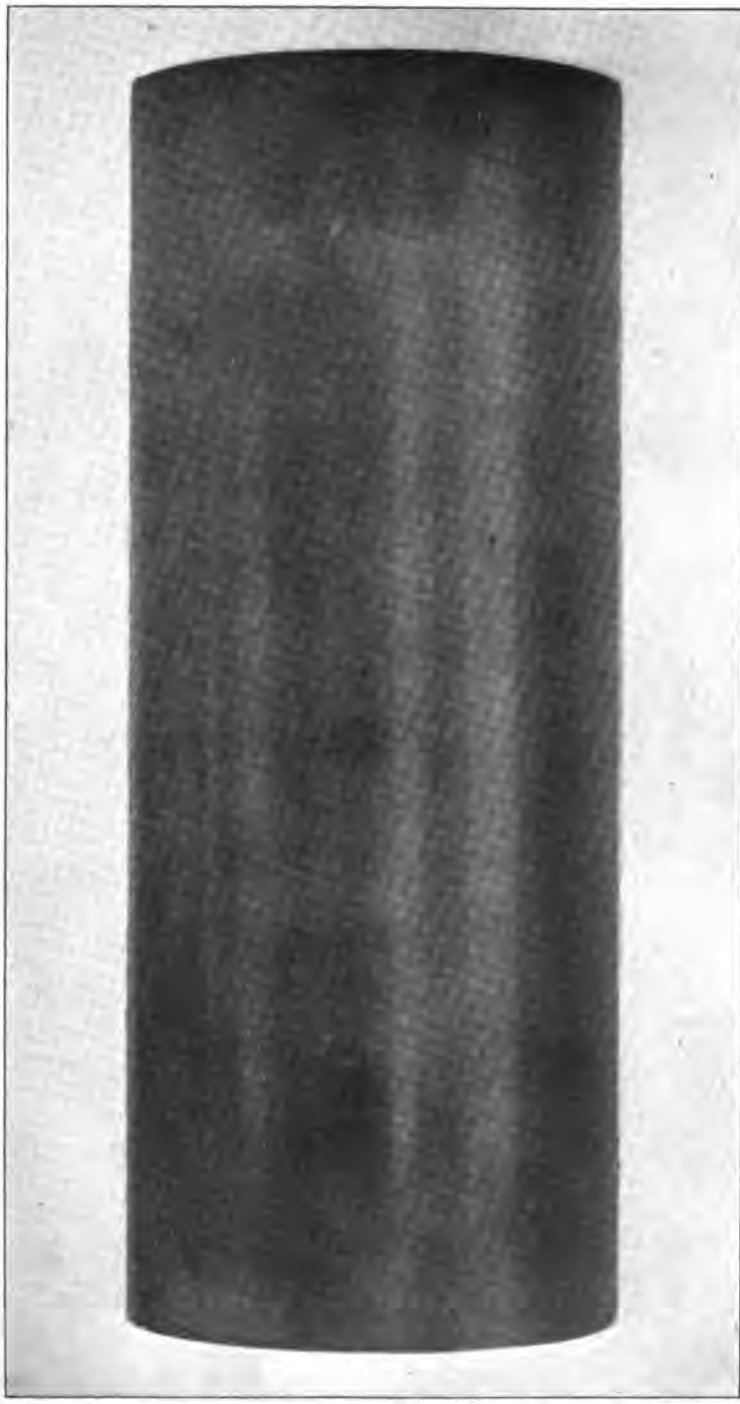
NOTE.—Specimens marked L were taken out longitudinally; specimens marked T were taken out tangentially.

FIFTH CASE.—3-INCH SHRAPNEL CASE C-1.

Case etched with iodine.
No streaks or seams visible before test.
Outside diameter of case, 2.97 inches.
Inside diameter of case, 2.63 inches.
Bored out for a length of 5.50 inches.
Depth inside, 6.98 inches.
Length over all outside, 7.40 inches.
Case entered testing cylinder 1 inch, leaving 4.50 inches length of reduced thickness of walls exposed to the interior pressure of the test.
Diameter of piston, 2.62 inches.
Sectional area, 5.39 square inches.

Applied loads.			Remarks.
Total pounds on piston.	Interior pressure (pounds per square inch).	Fiber stress on case (pounds per square inch).	
82,800	15,360	118,800	Ultimate strength.

Longitudinal rupture.
Fracture started near the top of case.
No streaks or seams visible.
Fracture appeared silky and lamellar.
Small checks developed in different parts of the case during the test.
This case made from hammered bar stock. Case heat treated after rough machining.



3-INCH SHRAPNEL CASE MARKED B-2. BEFORE TEST. CASE MADE FROM HEAT-TREATED HAMMERED BAR STOCK.

CASE L-2.

Applied loads.			Remarks.
Total pounds on piston.	Interior pressure (pounds per square inch).	Fiber stress on case (pounds per square inch).	
317,000	16,150	173,000	Ultimate strength.

Longitudinal rupture. Fracture started near the middle of case.
No streaks visible in fracture.
Appearance of fracture, silky and lamellar.

CASE U-2.

Applied loads.			Remarks.
Total pounds on piston.	Interior pressure (pounds per square inch).	Fiber stress on case (pounds per square inch).	
324,000	16,500	176,200	Ultimate strength.

Longitudinal rupture. Fracture started a little above the middle of case.
No streaks visible in fracture.
Appearance of fracture, silky and lamellar.

SHOCK TESTS.

Specimens taken from the walls of the case near the base gave the following tests on the Charpy machine:

Test piece marks.	Sectional area (square inch).	Charpy machine.		
		Excess angle.	Total foot-pounds.	Foot-pounds per square inch.
L 1 A....	0.0785	125.5	36.6	466.2
L 1 A....	.0780	125.5	36.6	469.1
L 1 B....	.0777	126.5	35.0	450.4
L 1 B....	.0780	127.0	34.2	438.4
U 1 A....	.0780	127.5	33.4	428.2
U 1 A....	.0780	126.0	35.8	458.9
U 1 B....	.0775	131.0	28.0	361.2
U 1 B....	.0773	127.5	33.4	429.1

The above results are much better than those obtained on previous tests. The impact strength is over 400, whereas the 6-inch, 3-inch, and 2.95-inch cases previously tested averaged below 200 foot-pounds per square inch.

MICROSCOPIC EXAMINATION.

The microscopic examination reveals a fine, uniform, troostitic structure. To determine whether the hardening was uniform throughout the mass, hardness numbers were taken on a cross section of the wall near the base. The metal was found to be very uniform, varying from 364 to 375 Brinell.

HYDROSTATIC TEST OF ONE 4.7-INCH SHRAPNEL CASE.

This shrapnel case was manufactured at Watertown Arsenal from a bar 6½ inches diameter.

Marks on case, 2. Case not etched.

Outside diameter of case, 4.68 inches.

Inside diameter of case, 4.28 inches.

Mouth of case not threaded.

Bored out for a length of 8.36 inches.

Depth inside, 10.85 inches.

Length over all outside, 11.54 inches.

Length from top to top edge of band groove, 8.74 inches.

Case entered testing cylinder, 1½ inches, leaving 6.86 inches length of reduced thickness of walls exposed to the interior pressure of the test.

Diameter of piston, 5.00 inches.

Sectional area, 19.63 square inches.

Applied loads.			Exterior diameter of case (inches).	Remarks.
Total pounds on piston.	Interior pressure (pounds per square inch).	Fiber stress on case (pounds per square inch).		
0	0	0	4.680	
5,000	255	.....	4.680	
120,000	6,115	65,500	4.680	
5,000	255	.....	4.680	
130,000	6,625	70,900	.....	
5,000	255	.....	4.680	
140,000	7,130	76,200	.....	
5,000	255	.....	4.681	
145,000	7,386	79,170	.....	
5,000	255	.....	4.701	
208,000	.....	113,570	.....	Ultimate strength.

Case flew into three fragments.

Appearance of fracture, fine granular.

HYDRAULIC CYLINDERS FOR 4.7-INCH HOWITZER.

HYDROSTATIC TEST OF HYDRAULIC CYLINDER FOR 4.7-INCH HOWITZER.

1. This cylinder was made from a forging of the following composition:

C	0.40
Mn	.609
Si	.247
P	.027
S	.020
Ni	3.62

The cylinder was annealed and rough machined to the dimensions shown in sketch No. 1. It was next quenched in oil from 775° C. and then drawn at 600° C. for four hours, followed by slow cooling in the furnace.

2. Three tensile specimens gave the following results:

Elastic limit (pounds per square inch).	Tensile strength (pounds per square inch).	Elongation (per cent).	Contraction (per cent).	Brinell hardness number.
90,500	115,500	22.0	64.7	241
93,000	115,500	21.0	57.2	241
93,500	116,000	22.0	62.3	241
[1] 92,330	[1] 115,830	[1] 21.7	[1] 61.4	[1] 241

[1] Average.

The specimens were all taken in a longitudinal direction.

3. Microscopic examination of the metal indicated a fine, uniform, sorbitic structure, free from slag streaks. (See photo No. 1.)

HYDRAULIC TEST.

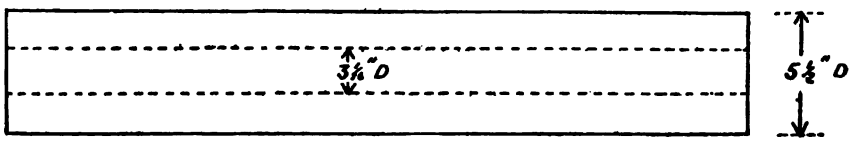
The cylinder, after heat treatment, was finished to an inside diameter of 5.08 inches, the outside diameter being 5.50 inches. The arrangement for testing is shown in sketch No. 2 and photographs No. 2 and No. 3.

The cylinder H, the connecting piping L, and the test cylinder K were filled with water, through the connection X. Hydraulic pressure was obtained by means of the piston P, U being a leather packing to prevent leakage. P and H were placed between the platforms of the testing machine, as indicated by the arrows.

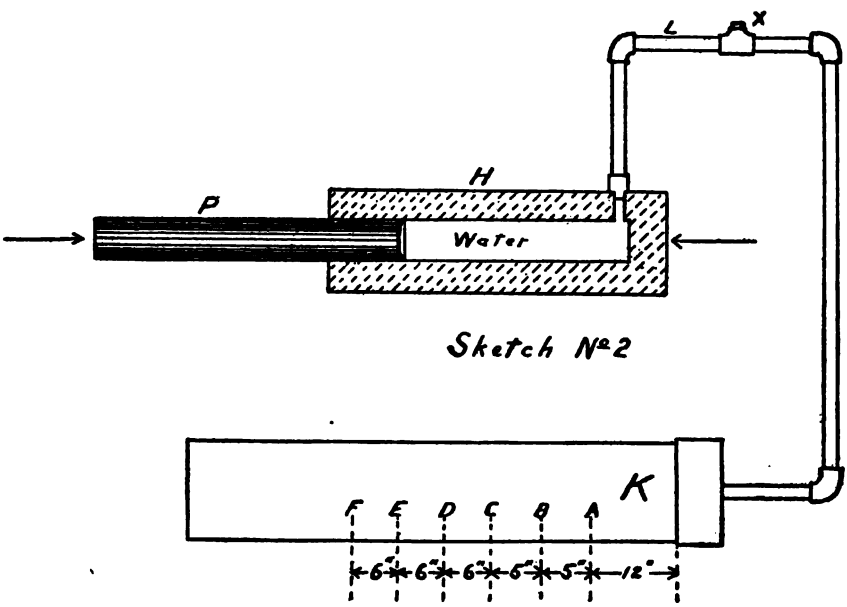
Measurements were taken of the outside diameter at points 6 inches apart, as indicated on sketch No. 2 at points A, B, C, D, E, and F. As the lowest elastic limit given by the three tensile specimens was 90,500, it was decided to stress the cylinder to 85,000 one hundred times, and then to determine whether there was a perma-

nent set. The formula for a thick hollow cylinder was used to compute the fiber stress in the walls. The table following gives the results obtained.

From the table it is seen that after stressing to 85,000 pounds per square inch 100 times there was no permanent set. The load was then gradually increased, measurements being taken each time after reducing the load to 3,750 pounds per square inch fiber stress. No permanent set was obtained until a fiber stress of 95,000 pounds was reached. This located the elastic limit between 93,500 and 95,000 pounds per square inch and agrees very closely with the results obtained on the tensile specimens.



Sketch No 1.



Sketch No 2

The cylinder finally burst at a fiber stress of 122,200, as calculated by the formula for a thick hollow cylinder. As this formula is only approximate above the elastic limit, the ratio of stress to strain no longer being constant, the result is considered to agree very well with the tensile test.

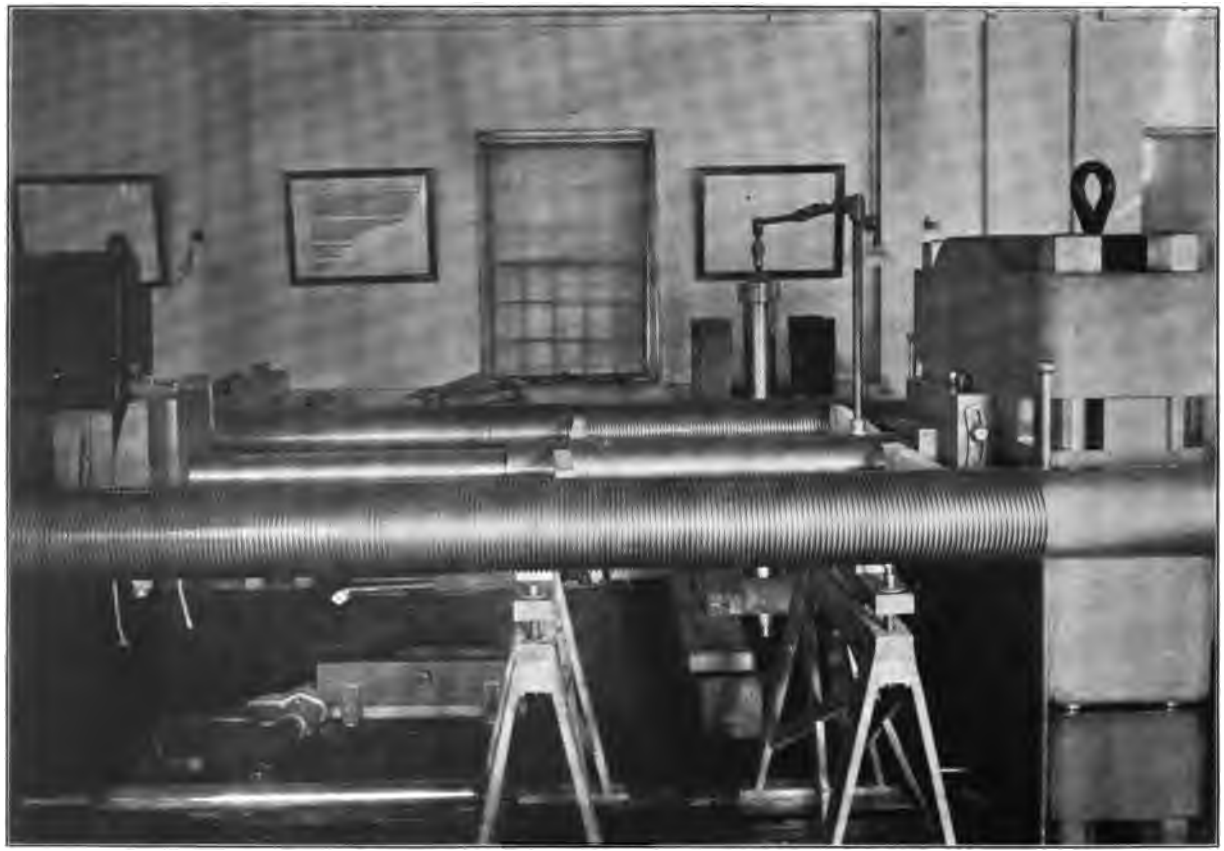
Photograph No. 4 gives a comparison of the cylinder under test (No. 1) and a cylinder which burst on acceptance test. (No. 2.) It will be noted that the fracture of No. 1 indicates a very ductile metal, while that in cylinder No. 2 is characteristic of brittle steel.

The tensile tests of cylinder No. 1 gave an average contraction of area of 61.4 per cent, whereas test specimens taken from the wall of the brittle cylinder gave a contraction of only 31.8 per cent and 27.5 per cent.

[Diameters in inches.]

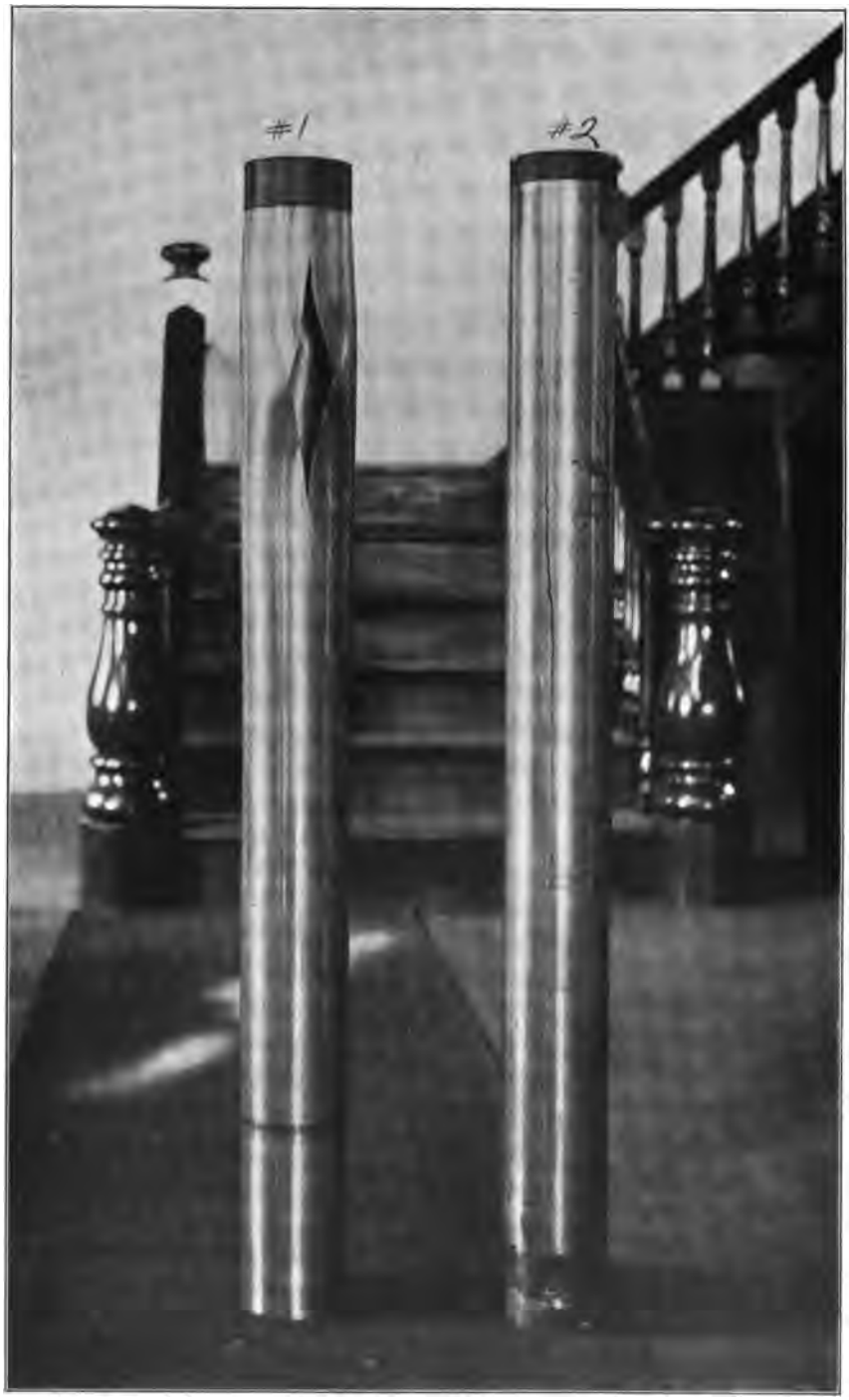
A.	B.	C.	D.	E.	F.	Load on machine (pounds).	Fiber stress on walls of cylinder.	Remarks.
5.5005	5.5005	5.5000	5.5005	5.5002	5.5000	6,000	3,750	
5.5075	5.5075	5.5070	5.5075	5.5070	5.5070	80,330	50,000	
5.5005	5.5007	5.5000	5.5005	5.5003	5.5000	6,000	3,750	
5.5085	5.5085	5.5085	5.5082	5.5080	5.5080	96,396	60,000	
5.5100	5.5100	5.5100	5.5098	5.5100	5.5100	112,500	70,000	
5.5120	5.5115	5.5110	5.5110	5.5105	5.5100	120,500	75,000	
5.5005	5.5005	5.5005	5.5000	5.5002	5.5003	6,000	3,750	
5.5115	5.5117	5.5115	5.5112	5.5115	5.5112	128,500	80,000	
5.5125	5.5100	5.5125	5.5120	5.5122	5.5118	136,600	85,000	
5.5005	5.5005	5.5000	5.5005	5.5002	5.5000	6,000	3,750	After stressing to 85,000 ten times.
5.5005	5.5005	5.5000	5.5005	5.5002	5.5000	6,000	3,750	
5.5125	5.5130	5.5125	5.5120	5.5120	5.5120	136,600	85,000	After stressing to 85,000 eleventh time.
5.5005	5.5005	5.5000	5.5005	5.5002	5.5000	6,000	3,750	After stressing to 85,000 twenty-five times.
5.5125	5.5120	5.5125	5.5120	5.5120	5.5120	136,600	85,000	After stressing 50 times.
5.5005	5.5005	5.5000	5.5005	5.5000	5.5000	6,000	3,750	Do.
5.5125	5.5130	5.5125	5.5125	5.5120	5.5120	136,600	85,000	After stressing 75 times.
5.5005	5.5005	5.5000	5.5005	5.5000	5.5000	6,000	3,750	Do.
5.5128	5.5130	5.5125	5.5122	5.5125	5.5120	136,600	85,000	After stressing 100 times.
5.5005	5.5007	5.5002	5.5005	5.5000	5.5125	6,000	3,750	Do.
5.5005	5.5007	5.5002	5.5005	5.5000	5.5000	145,400	3,750	After 90,500 fiber stress.
5.5005	5.5005	5.5002	5.5005	5.5000	5.5000	148,300	3,750	After 92,300 fiber stress.
5.5005	5.5005	5.5002	5.5000	5.5000	5.5000	150,300	3,750	E. L. After 93,500 fiber stress.
5.5010	5.5010	5.5002	5.5000	5.5002	5.5000	152,630	3,750	E. L. After 95,000 fiber stress.
5.5015	5.5012	5.5002	5.5000	5.5002	5.5000	155,800	3,750	After 97,000 fiber stress.
5.5020	5.5020	5.5007	5.5005	5.5008	5.5000	160,660	3,750	After 100,000 fiber stress.
5.5105	5.5065	5.5050	5.5030	5.5035	5.5020	168,700	3,750	After 105,000 fiber stress.
5.5680	5.5600	5.5400	5.5450	5.5475	5.5475	176,730	3,750	After 110,000 fiber stress.
5.6155	5.6155	5.5895	5.5930	5.5945	5.5945	184,760	3,750	After 115,000 fiber stress.
.....	.....	.....	.....	.....	.....	.....	.....	Burst at 122,200 fiber stress.

PHOTOGRAPH NO. 1. (×75.)



PHOTOGRAPH NO. 2.
4.7-inch Howitzer Recoil Cylinder ready for test.

PHOTOGRAPH NO. 3.
4.7-inch Howitzer Recoil Cylinder ready for test.



PHOTOGRAPH NO. 4. 4.7-INCH HOWITZER RECOIL CYLINDERS.

No. 1.—Satisfactory Cylinder, passed test, reported herein. No. 2.—Unsatisfactory Cylinder, failed on acceptance test.

HYDROSTATIC TEST OF SECOND HYDRAULIC CYLINDER FOR 4.7-INCH HOWITZER.

1. This cylinder was made from a forging of the following composition:

C	0.435
Mn	.707
Si	.270
S	.027
P	.015
Ni	3.48

The cylinder was annealed and rough machined to the dimensions shown in sketch No. 1. It was next quenched in oil at 800° C. and then drawn at 625° C. for four hours.

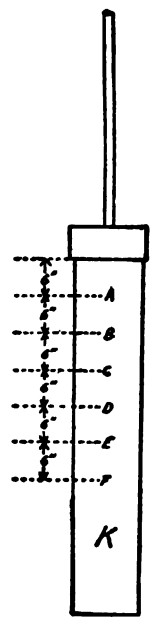
2. Two longitudinal tensile specimens gave the following results:

Marks.	Elastic limit (pounds per square inch).	Tensile strength (pounds per square inch).	Elongation.	Contraction.	Brinell hardness number.
			Per cent.	*Per cent.*	
5000 F L	80,500	109,000	24.5	59.8	228
5000 F I L	79,500	107,500	25.5	62.3	217
Average	80,000	108,250	25.0	61.0	222

3. Microscopic examination of the metal indicated a fine, uniform sorbitic structure, free from slag streaks. See photo No. 5.

HYDRAULIC TEST.

This cylinder was finished to nearly the dimensions noted in connection with first cylinder, the thickness of wall being 0.18 instead of 0.21 inch. The apparatus used was exactly as described for the first cylinder. Measurements of the outside diameter of the cylinder were taken at points 6 inches apart, marked A, B, C, D, E, and F on sketch No. 3.



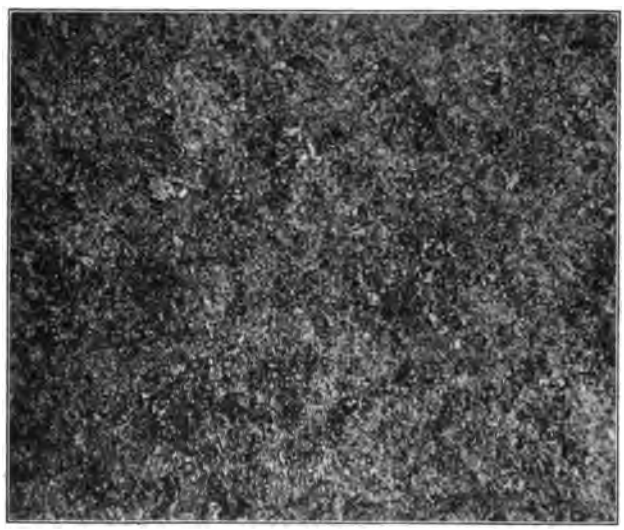
Sketch No. 3

As the elastic limit, determined by the tensile test, was 80,000 pounds per square inch, it was decided to apply the stress repeatedly at a fiber stress in the walls of 75,000.

The formula for a thick hollow cylinder,

$$f = P\left(\frac{R_1^2 + R_2^2}{R_1^2 - R_2^2}\right)$$

was used in determining fiber stresses. The attached table gives the results obtained. From the table it is seen that for points D, E, and F a slight permanent set was obtained after a fiber stress of 75,000 pounds per square inch. The cylinder was then stressed to this fiber stress 100 times, the permanent set increasing slightly. The load was then increased, as indicated, until at a stress of 88,500 pounds per square inch the cylinder burst.



PHOTOGRAPH NO. 5. (X75.)

This ultimate strength was below the 108,250 pounds indicated by the tensile test. No flaw or defect could be found in the fracture.

Applied loads.		Measurements of cylinder (inches).						Remarks.
Total pounds on piston.	Fiber stress on cylinder (pounds per square inch).	A.	B.	C.	D.	E.	F.	
6,000	4,380	5.498	5.496	5.498	5.498	5.498	5.498	
68,490	50,000	5.505	5.502	5.504	5.505	5.505	5.505	
6,000	4,380	5.498	5.496	5.498	5.498	5.498	5.498	
82,190	60,000	5.506	5.504	5.506	5.506	5.507	5.507	
6,000	4,380	5.498	5.496	5.498	5.498	5.498	5.498	
89,040	65,000	5.508	5.505	5.507	5.508	5.508	5.508	
6,000	4,380	5.498	5.496	5.498	5.499	5.498	5.498	
95,890	70,000	5.508	5.506	5.508	5.510	5.510	5.509	
6,000	4,380	5.498	5.496	5.498	5.499	5.499	5.499	
102,730	75,000	5.509	5.507	5.510	5.516	5.516	5.516	
6,000	4,380	5.498	5.496	5.500	5.505	5.505	5.505	
102,730	75,000	.....	.....	.....	.....	.....	.....	
6,000	4,380	5.498	5.496	5.500	5.506	5.506	5.506	After stressing 10 times.
102,730	75,000	5.509	5.507	5.512	5.516	5.516	5.516	At 11 times.
102,730	75,000	5.509	5.507	5.512	5.517	5.517	5.516	At 25 times.
6,000	4,380	5.498	5.496	5.500	5.506	5.506	5.506	After 25 times.
102,730	75,000	5.509	5.507	5.512	5.518	5.518	5.517	At 50 times.
6,000	4,380	5.498	5.496	5.501	5.508	5.507	5.507	After 50 times.
102,730	75,000	5.509	5.507	5.512	5.519	5.518	5.518	At 100 times.
6,000	4,380	5.498	5.496	5.502	5.509	5.508	5.507	After 100 times.
109,580	80,000	.....	.....	.....	.....	.....	.....	
6,000	4,380	5.498	5.496	5.503	5.509	5.509	5.508	After 80,000 pounds.
116,430	85,000	.....	.....	.....	.....	.....	.....	
6,000	4,380	5.498	5.503	5.524	5.529	5.530	5.528	After 85,000 pounds.
121,100	88,500	.....	.....	.....	.....	.....	.....	Ultimate strength.

Cylinder ruptured longitudinally. Rupture or fracture 21.50 inches long. Principal bulge was 17.25 inches from end of cylinder.

MATERIAL TESTS FOR 16-INCH DISAPPEARING CARRIAGE, MODEL OF 1912.

MATERIAL TESTS FOR 16-INCH DISAPPEARING CARRIAGE.

Structural parts of 16-inch disappearing carriage.

FORGED STEEL NO. 2.

Part.	Specimen mark.	Yield point (pounds per square inch).	Tensile strength (pounds per square inch).	Elongation (per cent).	Contraction (per cent).	Treatment.
Hand pinion	3309 F	47,500	85,500	28.0	46.2	Annealed at 595° C., 2 hours.
Pinion shafts	5124 F	66,500	106,000	23.5	46.2	Drawn at 600° C., 3 hours.
Roller pinions	3417 F	57,000	82,500	25.0	51.9	Annealed at 595° C., 2 hours.
Segments, trav. rack	4014 F	39,000	76,500	28.5	51.9	Annealed at 600° C., 3 hours.

FORGED STEEL NO. 3.

Part.	Specimen mark.	Purchase order number.	Yield point (pounds per square inch).	Tensile strength (pounds per square inch).	Elongation (per cent).	Contraction (per cent).	Treatment.
Bolts	5282 F	4795	59,000	96,000	25.5	51.9	Drawn at 600° C., 3 hours.
Cam (expeller) and ratchet.	3631 F	9700	55,000	104,500	20.0	40.3	Annealed at 595° C.
Collars, expelling	3415 F	9493	46,500	89,500	19.0	46.2	Annealed at 595° C., 3 hours.
Crown nuts and power pinion.	3315 F	9493	47,500	93,000	25.5	49.1	Annealed at 595° C., 2 hours.
Hooks, retracting	3350 F	8407	50,000	102,000	15.0	27.4	Do.
Levers, expelling	3379 F	9493	48,000	100,000	20.5	40.3	Annealed at 595° C.
Locks, pin	3615 F	9493	66,000	101,500	23.0	54.6	Annealed at 595° C., 2 hours.
Pawls	3283 F	2203	59,500	99,000	25.0	51.9	Do.
Do	3471 F	9493	62,000	97,000	21.5	46.2	Do.
Pinion, vertical shaft	3314 F	1574	52,500	100,500	22.0	37.2	Do.
Shaft, rocker, right and left.	3260 F	2252	53,000	95,500	25.0	51.9	Do.

FORGED STEEL "A".

Part.	Specimen mark.	Yield point (pounds per square inch).	Tensile strength (pounds per square inch).	Elongation (per cent).	Contraction (per cent).	Treatment.
Bolts	5038 F	65,000	111,000	23.5	57.2	Drawn at 600° C., held 3 hours.
Do	5016 F	64,500	109,000	23.5	57.2	Do.
Pinion pins	3617 F	64,500	112,000	22.0	51.9	Annealed at 595° C.
Pinion shafts	5155 F	58,000	93,000	29.0	57.2	Annealed at 600° C., 3 hours.
Special washer nut	4072 F	58,500	106,500	17.5	34.0	Do.

FORGED STEEL "B".

Pawls	3420 F	63,000	102,000	23.0	57.2	Annealed at 595° C. 2 hours.
Pawl pins	3358 F	65,000	106,500	22.0	51.9	Do.

FORGED STEEL "C".

Spring rods	3360-F-2	104,500	134,500	15.0	46.2	Oil quenched at 775° C. Annealed at 550° C., 2 hours.
Spring rod	3359 F-2	84,000	124,500	19.0	46.2	Oil quenched at 775° C. Annealed at 595° C., 2 hours.

FORGED STEEL "D".

Elev. pins and epicyclic pinion.	3352 F	104,000	135,500	15.0	46.2	Oil quenched at 775° C. Annealed at 500° C., 2 hours.

Structural parts of 16-inch disappearing carriage—Continued.

CAST STEEL NO. 2.

Part.	Heat number.	Specimen mark.	Yield point (pounds per square inch).	Tensile strength (pounds per square inch).	Elongation (per cent).	Contraction of area (per cent).	Treatment.
Axle bearings, stirrups, and traversing lock frames.	4,568	9126	44,000	82,500	21.5	27.4	Air chilled at 950° C., held 2 hours. Drawn at 500° C., 2 hours.
Bracket, rear, and standard.	4493	8512	44,500	86,000	19.0	20.5	Do.
Do	4501	8585	45,000	84,000	19.0	20.5	Do.
Bracket caps	[1] 4520	8748	46,500	85,500	24.5	34.0	Do.
Clip and traversing bracket.	4249	6123	50,000	88,500	17.0	27.4	Air chilled at 850° C.; air chilled at 765° C. Annealed at 500° C., 2 hours.
Clip (front) and center hinge support.	[1] 4132	4053	45,500	78,500	25.0	27.4	Air chilled from 675° C. after holding 3 hours.
Caps (trunnion bed) and elevating pinion.	[1] 4158	4530	42,500	78,500	23.5	30.7	Do.
Caps, trunnion bed	4164	4681	47,000	80,000	20.5	24.0	Air chilled at 950° C., held 2 hours. Drawn at 500° C., 2 hours.
Counterweight pin	[1] 4225	5803	49,500	87,000	19.0	27.4	Air chilled at 950° C.; air chilled at 765° C. Annealed at 500° C., 2 hours.
Counterweight pin and pinion shaft bracket.	4224	5872	47,500	81,000	15.0	20.5	Do.
Frame	4592	9458	41,000	80,500	14.0	20.5	Air chilled at 950° C., held 2 hours. Drawn at 500° C., 2 hours.
Do	4572	9186	44,500	86,000	21.0	27.4	Do.
Do	[1] 4574	9227	46,500	88,000	16.5	24.0	Do.
Gear, epicyclic	4309	6582	52,000	89,500	16.5	27.4	Air chilled at 950° C.; air chilled at 765° C. Annealed at 500° C., 2 hours.
Do	4403	7451	42,000	77,500	24.0	30.7	Air chilled at 950° C. Annealed at 600° C., 2 hours.
Gear, first	4500	8561	43,000	82,500	23.5	27.4	Air chilled at 950° C., held 2 hours. Drawn at 500° C., 2 hours.
Gear, power	4434	7890	41,000	80,500	20.5	27.4	Air chilled at 950° C. Annealed at 500° C., 2 hours.
Left gun levers and piston rod bracket.	4215	5819	50,000	88,500	16.0	20.5	Air chilled at 950° C.; air chilled at 765° C. Annealed at 500° C., 2 hours.
Pinion, elevating	[1] 4437	7909	42,500	80,000	20.0	27.4	Air chilled at 950° C. Annealed at 500° C., 2 hours.
Stirrups and elevating pinion.	[1] 4569	9138	42,500	84,000	21.0	27.4	Do.
Struts	[1] 4552	8945	41,500	80,000	18.5	27.4	Air chilled at 950° C., held 2 hours. Drawn at 500° C., 2 hours.

CAST STEEL NO. 3.

Box, pawl	[1] 4299	6534	51,000	98,500	13.0	20.5	Air chilled at 950° C.; air chilled at 765° C. Annealed at 500° C., 2 hours.
Box, pawl, and elevating slide.	4303	6562	56,000	95,500	11.5	16.9	Do.
Bracket, front	4467 4468	8266	49,500	89,000	16.5	20.5	Air chilled at 950° C., held 1 hour. Drawn at 500° C., 2 hours.
Caster	[1] 4587	9368	53,000	105,500	14.0	20.5	Air chilled at 950° C., held 2 hours. Drawn at 500° C., 2 hours.
Drum clutch and spring rod nut.	4173	4832	50,500	85,000	20.0	24.0	Air chilled at 950° C.; air chilled at 765° C. Annealed at 500° C., 2 hours.
Gear cage, epicyclic	4191	5157	47,500	92,500	16.5	20.5	Do.
Gear, epicyclic	4187	5068	48,000	85,500	17.5	20.5	Do.
Pinion	[1] 4482	8422	45,500	87,000	19.5	27.4	Air chilled at 950° C., held 2 hours. Drawn at 500° C., 2 hours.
Racks	4592	9458	41,000	80,500	14.0	20.5	Do.

[1] Chemical analysis given in table of analyses.

Structural parts of 16-inch disappearing carriage—Continued.

TYPICAL ANALYSES OF CAST STEEL.

Heat number.	Carbon (per cent).	Manganese (per cent).	Silicon (per cent).	Sulphur (per cent).	Phosphorus (per cent).
4132	0.46	0.64	0.256	0.049	0.046
4158	.31	.58	.140	.043	.034
4225	.53	.63			
4299	.45	.64			
4437	.47	.44			
4482	.36	.68			
4520	.37	.69	.235	.048	.037
4552	.39	.68			
4569	.40	.50			
4574	.42	.72			
4587	.41	.73			

BRONZE NO. 2.

Part.	Piece mark.	Tensile strength (pounds per square inch).	Elongation (per cent).	Contraction of area (per cent).
Bearings	1721	6,2400	20.5	23.0
Bearings	1732	6,0000	24.5	29.5
Bearings	1748	6,1600	19.0	23.0
Bearings	1764	5,9400	17.0	23.0
Bearings	1774	5,9200	41.5	39.6
Equalizing pipe connection	1660	6,2000	40.0	33.8
Shaft bushings	1633	6,0200	41.0	37.7

BRONZE NO. 3.

Buffer by-passes	1660	62,000	40.0	33.8

Structural parts of 16-inch disappearing carriage—Continued.

BRONZE NO. 4.

Part.	Piece mark.	Tensile strength (pounds per square inch).	Elongation (per cent).	Contraction of area (per cent).
Bearings and left side liner	1717	60,600	46.5	45.3
Bearings, bushing, cylinder heads, washers, and outer friction disks	3666	62,400	43.5	37.7
Bracket, rear bracket, gland nuts, bushings, rod ends, first pinions	3708	61,600	39.5	33.8
Bushings, gland nuts, rod end, short levers, long lever, glands, helix bushing, cup bushings and rear ends	3679	57,400	24.0	25.2
Buffer, counter recoil	5294F	61,800	36.0	33.8
Bushings	3590	59,200	42.5	37.7
Bushing	3603	63,400	36.0	33.8
Bushings	3567	62,200	41.0	37.7
Bushing and pawl bushings	3506	64,000	31.0	29.5
Bushing	3215	59,800	44.0	41.6
Bushings and follower	1633	60,200	41.0	37.7
Bushings	1622	62,600	42.5	41.6
Bushings	1579	60,400	36.0	31.6
Bushing	3167	67,400	17.5	18.6
Bushing	3160	66,000	14.0	39.6
Bushings	3021	62,000	27.5	33.8
Bushings	2893	63,000	36.5	33.8
Bushings	1642	61,200	36.5	33.8
Bushing, axle bed	2301	64,000	42.5	39.6
Bushing, axle bed	2558	61,800	40.5	33.8
Bushing, axle bed	2296	58,200	31.5	27.4
Bushing, collars, nut liner, retaining collar, back gear bushing	1660	62,000	40.0	33.8
Bushings (axle bed) and valve disks	2298	61,200	37.5	31.6
Bushing (sheave) and stop dogs	2857	60,000	45.0	41.6
Buffer by-passes	2180	61,600	37.5	29.5
Buffer by-pass	3087	64,800	25.5	31.6
Buffer by-pass	3055	67,000	27.5	29.5
Buffer by-pass	3035	66,400	29.0	29.5
Buffer by-pass	3234	68,400	22.0	20.8
Buffer by-pass	3228	66,800	20.0	23.0
Buffer by-pass	3617	63,600	40.0	41.6
Gland, stuffing box	3326	61,800	37.5	33.8
Follower	1629	62,400	35.0	35.7
Handwheel pinion and inclined shaft pinion	2290	63,200	33.5	29.5
Range rack (Tobin bronze)	3846F	60,600	35.5	33.8
Stop dog	2950	62,800	37.0	33.8
Side liner, right	1714	63,800	42.0	41.6
Traversing clutch	2293	61,600	41.0	37.7

WIRE ROPE.

TENSILE TESTS OF WIRE ROPE.

Rope prepared for testing with closed sockets at the ends. All specimens had hemp cores.

Description.	Nominal size, diameter.	Length between sockets.	Actual size, diameter.	Number of strands.	Number of wires per strand.
	Inches.	*Ft. In.*	*Inches.*		
Phosphor bronze tiller rope	¼	3 0	0.25	6	7
Do [1]	¼	2 6	.25	6	7
Do	¼	3 0	.25	6	7
Steel wire rope	⅜	9 1	.38	6	19
Steel wire hoisting rope	⅜	9 5	.38	6	19
Plow steel rope	⅜	9 6	.37	6	37
Plow steel crane rope	⅜	9 7	.38	6	37
Do	⅜	9 7	.37	6	37
Do	⅜	9 7	.37	6	37
Do	⅜	9 5½	.38	6	37
Steel wire rope	⅜	9 7	.37	6	37
Cast steel hoisting rope	½	9 3½	.52	6	19
Cast steel wire rope	½	9 6	.52	6	19
Cast steel hoisting rope	7/16	9 5	.59	6	19
Plow steel hoisting rope	7/16	9 2½	.60	6	37
Plow steel crane rope	7/16	9 3½	.58	8	19
Do	7/16	9 2½	.58	8	19
Do	7/16	9 5	.59	8	19
Steel wire hoisting rope	7/16	9 6	.58	6	19
Do	7/16	5 4	.58	8	19
Do	7/16	9 5	.59	8	19
Do	7/16	2 0	.60	8	19
Do	7/16	9 3	.59	8	19
Do	7/16	9 3½	.60	8	19
Steel wire rope	½	9 7½	.81	8	19
Steel wire hoisting rope	½	9 5	.78	6	37
Steel wire rope	½	9 4½	.78	6	19
Plow steel crane rope	½	9 2½	.89	6	19
Plow steel wire rope	½	9 7	.93	8	19
Do	½	9 4½	.90	8	19
Plow steel hoisting rope	1.00	9 3	1.02	8	19
Do	1.25	5 1½	1.24	8	19
Steel wire hoisting rope	1.75	9 2	1.75	6	37

[1] Rope was wound around a 1½-inch bar with ends fastened.

Tensile tests of wire rope—Continued.

Description.	Diameter of wire.	Breaking strength.	Parted.
	Inches.	*Pounds.*	
Phosphor bronze tiller rope	.009	1,730	4 ropes at the fixture.
Do[1]	.009	1,250	2 ropes at the pin or bar.
Do	.009	1,170	4 ropes at the socket.
Steel wire rope		9,000	3 strands at middle of length.
Steel wire hoisting rope	.023-.027	11,100	4 strands 13 inches from end of socket.
Plow steel rope		10,900	4 strands at middle of length.
Plow steel crane rope		10,300	3 strands at middle of length.
Do	.015-.018	10,300	6 strands at end of socket.
Do	.015-.018	10,600	5 strands 12 inches from end of socket.
Do	.041-.044	11,800	5 strands at middle of length.
Steel wire rope	.016-.020	11,600	Do.
Cast steel hoisting rope	.033-.037	19,000	3 strands 30 inches from end of socket.
Cast steel wire rope		19,100	4 strands 12 inches from end of socket.
Cast steel hoisting rope		22,400	3 strands 32 inches from end of socket.
Plow steel hoisting rope	.027-.029	29,900	3 strands 12 inches from end of socket.
Plow steel crane rope	.023-.034	22,300	3 strands 24 inches from end of socket.
Do		23,400	4 strands 33 inches from end of socket.
Do	.025-.032	23,300	6 strands at end of socket.
Steel wire hoisting rope	.032-.042	21,200	3 strands near middle of length.
Do	.025-.032	24,500	5 strands at end of socket.
Do	.023-.034	22,800	3 strands at middle of length.
Do		23,800	Do.
Do	.029-.034	22,000	4 strands 12 inches from end of socket.
Do	.029-.034	24,400	Do.
Steel wire rope	.042-.047	40,200	4 strands at middle of length.
Steel wire hoisting rope	.034-.036	51,800	3 strands 6 inches from end of socket.
Steel wire rope	.040-.056	37,500	3 strands 15 inches from end of socket.
Plow steel crane rope	.048-.067	58,800	4 strands at end of socket.
Plow steel wire rope	.046-.049	57,800	6 strands at end of socket.
Do	.047-.049	50,100	5 strands from end of socket.
Plow steel hoisting rope	.052-.055	68,600	4 strands at middle of length.
Do	.050-.075	113,100	2 strands 14 inches from end of socket.
Steel wire hoisting rope	.068-.097	204,000	2 strands 10 inches from end of socket.

MANILA ROPE.

TENSILE TESTS OF MANILA ROPE (3 STRAND).

Rope prepared for testing with eye splices at the ends, and then wetting the rope.

Nominal size.		Length of sample.	Length between splices.	Weight of sample.	Breaking length.	Circumference.	Diameter.	Sectional area.
Diameter.	Circumference.							
Inch.	*Inches.*	*Ft. in.*	*Feet.*	*Lbs. ozs.*	*Feet.*	*Inches.*	*Inches.*	*Sq. in.*
⅛	.....	18 0	5-6	0 12	29,700	1.25	0.39	0.119
⅛	.....	16 1	6	0 9	30,020	1.20	.38	.113
⅛	.....	18 0	6	0 8	47,520	1.08	.34	.091
⅛	.....	.....	6	.....	.....	1.17	.37	.107
¼	.....	18 0	6	1 6	32,720	1.62	.53	.22
¼	.....	18 0	6	1 6	40,600	1.81	.56	.246
½	.....	18 0	6	3 5	30,960	2.70	.84	.553
1.00	.....	18 0	6	4 11	34,368	3.15	1.08	.833
3.50	.....	.....	3	.....	.....	12.40	4.15	13.53
3.50	.....	18 0	5-6	59 0	24,830	11.80	3.90	11.94
	2.00	18 0	6	2 2	28,800	2.15	.69	.374
	2.00	18 0	6	2 5	33,456	2.20	.71	.395
	2.00	18 0	6	.....	.....	2.10	.69	.374
	2.50	18 0	6	2 4	31,000	2.70	.88	.608
	2.50	18 0	6	3 2	29,370	2.50	.82	.53
	3.00	18 0	6	4 5	30,000	.....	1.00	.785
	3.00	18 0	6	4 9	29,970	3.10	1.02	.82
	3.00	18 0	6	5 0	32,752	3.25	1.01	.80
	3.00	18 0	6	4 15	31,340	3.20	1.03	.833
	3.00	18 0	6	.....	.....	3.20	1.07	.90
	4.00	18 7	5-6	9 0	29,110	4.40	1.45	1.65
	4.00	18 0	6	8 4	32,700	4.20	1.42	1.58
	4.00	18 0	6	8 4	32,200	4.18	1.42	1.58
	4.00	18 0	6	8 1	31,200	4.15	1.41	1.56
	4.00	18 0	6	8 6	30,300	4.32	1.41	1.56
	4.00	18 0	6	8 6	30,060	4.35	1.43	1.60
	4.00	.....	6	.....	.....	4.40	1.45	1.65
	4.00	.....	6	.....	.....	4.34	1.43	1.60
	4.00	.....	6	.....	.....	4.25	1.41	1.56
	4.00	.....	6	.....	.....	4.34	1.43	1.60
	4.50	18 0	6	.....	.....	4.75	1.58	1.96
	5.00	18 0	6	13 0	30,870	5.55	1.83	2.63
	5.00	18 0	6	12 14	30,330	5.40	1.82	2.60
	5.00	18 0	6	12 4	26,150	5.35	1.82	2.60
	6.00	18 0	6	18 12	31,970	6.75	2.20	3.80
	7.00	18 0	6	25 8	29,080	7.95	2.61	5.35
	7.00	17 8	6	25 8	32,800	7.30	2.45	4.71

Tensile tests of Manila rope (3 strand)—Continued.

Nominal size.		Tensile strength.		Parted.
Diameter.	Circumference.	Load.	Stress (pounds per square inch).	
Inch.	*Inches.*	*Pounds.*	*Pounds.*	
⅛	.....	2,200	10,084	1 strand at the splice.
3/16	.....	1,400	12,390	1 strand 18 inches from end of splice.
¼	.....	1,320	14,500	1 strand 12 inches from end of splice.
5/16	.....	1,500	14,018	1 strand 15 inches from end of splice.
⅜	.....	2,500	11,360	1 strand 21 inches from end of splice.
7/16	.....	3,100	12,600	1 strand 7 inches from end of splice.
½	.....	5,700	10,300	1 strand 27 inches from eye.
1.00	.....	8,700	10,444	1 strand at end of splice.
3.50	.....	105,000	7,766	Do.
3.50	.....	81,400	6,817	1 strand in the splice.
	2.00	3,400	9,090	1 strand at the splice.
	2.00	4,300	10,886	1 strand in the middle.
	2.00	4,000	10,695	1 strand at end of splice.
	2.50	6,200	10,197	1 strand 5 inches from end of splice.
	2.50	5,100	9,622	1 strand 8 inches from end of splice.
	3.00	7,200	9,170	1 strand 13 inches from end of splice.
	3.00	7,600	9,268	1 strand 19 inches from end of splice.
	3.00	9,100	11,375	1 strand at the splice.
	3.00	8,600	10,324	1 strand at end of splice.
	3.00	9,900	11,000	Do.
	4.00	14,100	8,545	1 strand at the splice.
	4.00	15,000	9,490	1 strand 10 inches from end of splice.
	4.00	14,800	9,360	1 strand 16 inches from end of splice.
	4.00	13,900	8,910	1 strand 14 inches from end of splice.
	4.00	14,100	9,038	1 strand 18 inches from end of splice.
	4.00	14,000	8,750	1 strand 11 inches from end of splice.
	4.00	12,200	7,393	1 strand 13 inches from end of splice.
	4.00	13,000	8,125	2 strands 17 inches from end of splice.
	4.00	13,300	8,525	1 strand 31 inches from end of splice.
	4.00	12,700	7,937	1 strand 36 inches from end of splice.
	4.50	15,600	7,959	1 strand 28 inches from end of splice.
	5.00	22,300	8,479	1 strand at the splice.
	5.00	21,700	8,346	1 strand 15 inches from end of splice.
	5.00	17,800	6,846	1 strand 14 inches from end of splice.
	6.00	33,300	8,763	1 strand 18 inches from end of splice.
	7.00	41,200	7,700	1 strand at the splice.
	7.00	35,100	7,452	1 strand in the splice.

WOOD.

TRANSVERSE TESTS OF ASH FOR WATERTOWN ARSENAL.

All specimens supported 24 inches apart and loaded at the middle.

Number.	Material.	Dimensions.			Ultimate strength.	
		Length.	Width.	Depth.	Total load.	Modulus of rupture (pounds per square inch).
		Inches.	*Inches.*	*Inches.*	*Pounds.*	
1	New England white ash	28.00	2.55	2.53	5,100	11,250
2	Arkansas ash	28.00	2.53	2.54	5,600	12,354
3	do	29.00	2.50	2.50	3,500	8,080
4	do	29.00	2.51	2.51	3,550	8,080
5	New England white ash	28.00	2.55	2.53	5,100	11,250
6	Arkansas ash	28.00	2.53	2.54	5,600	12,354
7	Western ash	25.95	2.50	2.50	4,300	9,900
8	Arkansas ash	29.00	2.50	2.50	5,253	12,100
9	do	29.00	2.50	2.50	4,284	9,870
10	do	29.00	2.50	2.50	4,896	11,280
11	do	29.00	2.48	2.50	4,182	9,713
12	do	29.00	2.50	2.50	4,488	10,340

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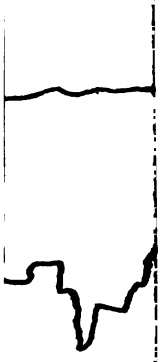


1. 9

PAPER.

TENSILE TESTS OF BLUE AND BROWN PRINT PAPER.

Strips 1 inch wide were cut from the paper in the rolling direction, or longitudinally.

Length of samples over all, 6½ inches. Length between clamps, 3 inches.

Paper tested both in the exposed and in the unexposed state.

Specifications for blue-print paper.

[Blue-print paper to be about 0.0042 inch thick, and possess a tensile strength of not less than 5,000 pounds per square inch. Test strips to be 1 inch wide and cut in the rolling direction of the paper.]

UNEXPOSED SAMPLES.

Samples.	Dimensions.		Sectional area.	Tests.			Mean.	Tensile strength per square inch.
	Width.	Thickness.		1	2	3		
	Inch.	*Inch.*	*Sq. in.*	*Lbs. Ozs.*	*Lbs. Ozs.*	*Lbs. Ozs.*	*Lbs. Ozs.*	*Pounds.*
A	1.00	0.0047	0.0047	25 6	24 14	24 1	24 12	5,260
B	1.00	.0043	.0043	30 9	28 4	29 5	29 6	6,830
C	1.00	.0053	.0053	25 12	25 4	26 4	25 12	4,850
D	1.00	.0041	.0041	22 13	21 13	21 2	21 15	5,350
E	1.00	.0051	.0951	23 8	23 8	23 6	23 7½	4,590
F	1.00	.0052	.0052	25 9	26 13	25 9	25 15½	4,990
G	1.00	.0056	.0056	30 12	29 6	31 8	30 8½	5,450
H	1.00	.0057	.0057	22 5	22 4	21 15	22 2½	3,880
J	1.00	.0046	.0046	28 6	28 0	28 2	28 2½	6,120
L	1.00	.0052	.0052	21 2	21 15	21 15	21 10½	4,160

EXPOSED SAMPLES.

A	1.00	0.0050	0.0050	24 8	24 13	24 6	24 9	4,910
B	1.00	.0045	.0045	27 13	29 1	29 12	28 14	6,410
C	1.00	.0054	.0054	26 3	25 2	24 1	25 2	4,650
D	1.00	.0042	.0042	23 3	21 0	21 2	21 12½	5,180
E	1.00	.0053	.0053	22 4	24 0	23 12	23 5½	4,400
F	1.00	.0053	.0053	24 13	22 14	24 0	23 14½	4,500
G	1.00	.0058	.0058	29 8	29 13	30 2	29 13	5,140
H	1.00	.0060	.0060	23 5	24 6	25 4	24 5	4,052
J	1.00	.0048	.0048	31 12	32 0	30 8	31 6½	6,540
K	1.00	.0052	.0052	23 12	26 8	23 12	24 10½	4,740
L	1.00	.0053	.0053	22 11	23 10	22 10	22 15½	4,330

Specifications for brown-print paper.

[Brown-print paper to be about 0.003 inch thick, and possess a tensile strength of not less than 7,000 pounds per square inch. Test strips to be 1 inch wide and cut from paper in the rolling direction.]

UNEXPOSED SAMPLES.

Samples.	Dimensions.		Sectional area.	Tests.			Mean.	Tensile strength per square inch.
	Width.	Thickness.		1	2	3		
	Inch.	*Inch.*	*Sq. in.*	*Lbs. Ozs.*	*Lbs. Ozs.*	*Lbs. Ozs.*	*Lbs. Ozs.*	*Pounds.*
A	1.00	0.0027	0.0027	11 11	11 1	11 4	11 5½	4,190
B	1.00	.0031	.0031	17 0	16 15	17 14	17 4½	5,560
C	1.00	.0030	.0030	20 8	20 11	21 9	20 14⅔	6,960
E	1.00	.0030	.0030	19 4	20 1	20 10	19 7⅔	6,490
F	1.00	.0030	.0030	21 8	20 2	21 8	21 ⅔	7,010
G	1.00	.0028	.0028	14 11	14 12	15 0	14 13	5,290
H	1.00	.0038	.0038	19 14	19 11	19 2	19 9	5,140
J	1.00	.0032	.0032	19 2	18 10	18 15	18 14⅓	5,900
K	1.00	.0038	.0038	23 13	23 7	26 2	24 7⅓	6,430
L	1.00	.0029	.0029	18 13	19 11	18 12	19 1⅓	6,580

EXPOSED SAMPLES.

A	1.00	0.0027	0.0027	12 0	11 3	11 5	11 8	4,250
B	1.00	.0033	.0033	18 13	19 3	18 9	18 13⅔	5,710
C	1.00	.0030	.0030	23 6	22 13	21 3	22 7⅓	7,480
E	1.00	.0032	.0032	19 2	19 10	18 13	19 3	5,990
F	1.00	.0030	.0030	20 6	19 8	19 7	19 12⅓	6,590
G	1.00	.0028	.0028	14 15	15 8	16 1	15 8	5,530
H	1.00	.0035	.0035	20 12	20 4	19 14	20 4⅔	5,790
J	1.00	.0030	.0030	20 4	20 11	20 12	20 9	6,850
K	1.00	.0038	.0038	24 15	25 9	24 11	25 1	6,590
L	1.00	.0031	.0031	20 8	21 5	20 14	20 14⅓	6,740

EJECTION OF SHRAPNEL CONTENTS.

TESTS TO ASCERTAIN THE PRESSURE REQUIRED TO FORCE OUT THE BALLS, MATRIX, AND SHRAPNEL HEAD FROM FIFTEEN 4.7-INCH SHRAPNEL CASES.

These tests were made in the large Emery testing machine. The test cases were held by rotating band seat in a special hollow anvil and the pressure applied to a plunger resting against the contents and extending through the cases.

Cases 1 to 5, inclusive, had all of the threads on the head.
Cases 6 to 10, inclusive, had half of the threads on the head.
Cases 11 to 15, inclusive, had no threads on the head.
All heads were pinned to the case.

Marks.	Pressure required (pounds).	Manner of failure.
1	28,800	Sheared 1 pin, tore out other pinhole, and sheared tops of threads in head.
2	39,100	Sheared both pins and tops of threads in head.
3	59,200	Do.
4	75,600	Head not pinned to case; sheared tops of threads in head.
5	111,500	Sheared 1 pin, tore out other pinhole and sheared tops of threads in head.
6	26,200	Sheared 1 pin, tore out other pin, and sheared tops of threads in head.
7	47,500	Pins not effective; pinholes too near edge of head; sheared tops of threads in head.
8	42,600	Do.
9	21,300	Sheared both pins and threads in head.
10	16,900	Sheared both pins and tops of threads in head.
11	7,800	Sheared 1 pin; bent the thin portion of head at opposite side, and dragged pin through hole in case.
12	10,700	Sheared 1 pin, tore out both pinholes in head.
13	8,700	Do.
14	12,300	Tore out both pinholes in head.
15	13,200	Sheared both pinholes in head.

TESTS OF BOILER PLATE.

TESTS OF BOILER PLATE.

The object of these tests was to secure information to aid in designing riveted joints, particularly with reference to the strength along the diagonal lines between rows of rivets, or, that is, determine what the minimum distance between rows may be in order to make sure that the joint will fail through the net section along the line of rivets in one row, rather than along the zig-zag diagonal lines. The test specimens were prepared by the International Engineering Works, under the direction of Mr. J. W. F. Macdonald.

The first 10 specimens were arranged with a constant net section of material 4 inches wide by $\frac{3}{8}$ inch thick, only with the lines through this net section placed at different angles to the line normal to stress, varying from 0° to 90° in increments of 10°. The purpose of this series of 10 was to secure data so as to plot a curve giving the relative strength of the material for the different angles, from which the proportion of metal necessary along the diagonal lines could be found directly.

Specimens Nos. 11 to 21, inclusive, were arranged with holes representing two or more rows of rivets spaced at different distances apart, that is, with varying proportions between the net amount of material along the diagonal lines, and that straight across between the two holes in the same line. These specimens were arranged in groups with Nos. 11, 12, 13, 14, and 15 having the same pitch of 4 inches and representing what would be typical spacing in the inner rows of riveted joints. Nos. 16, 17, and 18 represent the rivet holes in the two outer rows of the ordinary type of quadruple butt joint with an outer pitch of 15 inches. Nos. 19, 20, and 21 represent the rivet holes inside the calking edge of the saw-tooth type of quadruple butt joint with an outer pitch of 12 inches. The comparison of metal in each was as follows:

Specimen No. 11 area section diagonally=100 per cent area section straight across.
Specimen No. 12 area section diagonally=112½ per cent area section straight across.
Specimen No. 13 area section diagonally=120 per cent area section straight across.
Specimen No. 14 area section diagonally=133⅓ per cent area section straight across.
Specimen No. 15 area section diagonally=150 per cent area section straight across.
Specimen No. 16 area section diagonally=98 per cent area section straight across.
Specimen No. 17 area section diagonally=105 per cent area section straight across.
Specimen No. 18 area section diagonally=110 per cent area section straight across.
Specimen No. 19 area section diagonally=112½ per cent area section straight across.
Specimen No. 20 area section diagonally=133⅓ per cent area section straight across.
Specimen No. 21 area section diagonally=150 per cent area section straight across.

Specimen No. 16 is typical of actual conditions often found in the regular design of quadruple butt joints used throughout the United States, in which, in many cases, there is actually less material along the diagonal lines between the two outer rows than directly between rivets in the outer row, a condition given no consideration in the various rules for calculating such joints.

Where the same thickness of plate was used, test specimens were all cut from the same slab, so as to have as uniform conditions as possible. It will be noted that the actual results in the first 10 specimens showed remarkable uniformity, particularly with reference to the yield point as indicated by the first scaling of the plate and drop of the beam.

Tables No. 1 and No. 2 give the dimensions of specimens ultimate, loads, loads per square inch, etc.

Curves No. 1 and No. 2 were plotted with the ultimate strength and yield point as ordinates and different angles as abscissae. From these curves, it will be noted that the strength per square inch dropped off almost uniformly as the angle increased; or, that is, as the conditions varied from direct tension to direct shear.

Curve No. 3 was plotted to represent the ultimate strength for each angle in per cent of the strength of the same section normal to stress.

Curve No. 4 represents the increase in area of section necessary so that it will equal the strength of section normal to stress. For example, if the angle which the diagonal lines make with the line along the row of rivets is 30°, the results of these tests would indicate that the area of material diagonally should be increased 20 per cent. This curve can be used directly as a guide in the design of almost any riveted structure using staggered rows where it is necessary to decide on a proper diagonal pitch.

Specimen No. 11, in which the area diagonally just equalled that straight across between rivets, failed, as was expected, diagonally through the three holes.

Specimen No. 12 showed up stronger along the line straight across between the two holes than would be indicated from the results found in the first 10 specimens, the ultimate failure being straight across. If, however, the specimens were prepared with a riveted connection, where the holes were forced to retain their full width and the metal prevented from flowing to as great an extent as it did as shown by the elongation of the holes along the line of stress and contracting transversely, the results would probably have agreed more closely with the plotted curve. Again, in these specimens, the material was given more opportunity to stretch where its continuity was not wholly broken, than if the stress was transferred from one plate to the other by means of rivets as shown in figures No. 1 and No. 2.

Specimen No. 13 was watched with especial interest as the proportions conformed to that required as a minimum by the Canadian Rules, and also the recent A. S. M. E. Code. Here again the material showed up a little stronger diagonally than indicated by the curve No. 4, probably for the same reason already referred to.

Specimens Nos. 14 and 15, as was expected, broke directly across, the third hole showing less deformation as the proportion of material increased diagonally.

Specimen No. 16 failed along the diagonal lines—that is, broke through the three holes and at an ultimate load far below what would be the calculated strength according to the methods used in the various boiler rules.

Specimens Nos. 17 and 18 each failed straight across between the two holes, although the material around the central hole in No.

17 was very much distorted. These results again showed up stronger diagonally than would be indicated by curve No. 4. The distance between rows, however, in both of these specimens was much greater than the usual dimensions in practice, the back pitch in No. 18 probably being too wide for practical use.

Specimens Nos. 19, 20, and 21 all failed straight across between the two outer holes. The holes in No. 19 were very much distorted before ultimate failure, and if the same proportions were used in an actual joint it would probably fail diagonally, as shown in other tests which have been made on complete riveted specimens of this design.

Another feature to be noted in these tests was that in several of the samples which failed straight across, the yield point as indicated by the first scaling of the plate was first very clearly shown along the diagonal lines, which under the conditions would perhaps be the proper criterion for judging the weakest section.

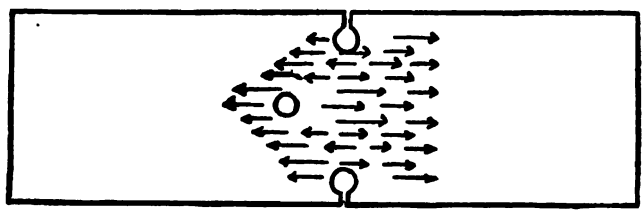


Fig. 1.

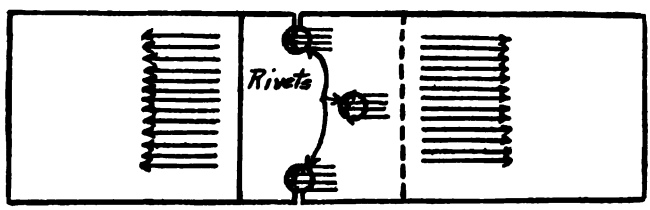


Fig. 2.

Another important point to be noted is that in the narrow specimens Nos. 12, 13, 14, and 15, with a 4-inch pitch, the ultimate strength came fully up to that which might be expected from the mill test report reproduced in Table No. 3, but as the specimens grew wider they fell far below. In specimens Nos. 19, 20, and 21 the calculated strength as compared with the solid plate should be 92.1 per cent, but actually was only 87.3 per cent, 87.5 per cent, and 89.5 per cent, and in specimens Nos. 16, 17, and 18, where the strength should be 94.1 per cent of the solid plate, it actually was only 81 per cent, 84.6 per cent, and 83.1 per cent.

In general, these tests will perhaps open up the way for further research along this line, and for the present curve No. 4 should give a good basis for proportion in this question of back pitch.

TABLE NO. 1.—*Results of tests made at Watertown Arsenal, Apr. 10, 1915, specimens 1 to 10, inclusive.*

No. of specimen.	Dimensions of net section.			Angle which line through net section makes with line normal to stress.	Yield point.		Ultimate strength.		Ultimate strength in per cent of strength of section normal to stress.	Increase in area of section necessary so that it will equal the strength of section normal to stress.
	Width.	Thickness.	Area.		Load on specimen.	Load per square inch.	Load on specimen.	Load per square inch.		
	Inches.	*Inch.*	*Sq. in.*	*Degrees.*	*Pounds.*	*Pounds.*	*Pounds.*	*Pounds.*	*Per cent.*	*Per cent.*
1	4.0	0.38	1.52	0	62,200	41,800	96,400	63,400	100.0	0
2	4.0	.39	1.56	10	57,100	36,600	92,700	59,400	93.6	6.8
3	4.0	.38	1.52	20	51,100	33,600	87,400	57,500	90.7	10.2
4	4.0	.38	1.52	30	45,000	29,600	81,000	53,300	84.0	19.0
5	4.0	.39	1.56	40	40,500	25,900	78,100	50,100	79.0	26.5
6	4.0	.39	1.56	50	37,500	24,000	74,900	48,000	75.7	32.1
7	4.0	.39	1.56	60	32,800	21,000	71,000	45,500	71.7	39.4
8	4.0	.39	1.56	70	29,200	18,700	70,500	45,200	71.2	40.4
9	4.0	.38	1.52	80	27,900	18,350	71,900	47,300	774.6	734.0
10	4.0	.38	1.52	90	26,900	17,700	63,100	41,500	65.5	52.7

TABLE NO. 2.—*Results of tests made at Watertown Arsenal Apr. 10, 1915, specimens 11 to 21, inclusive.*

No. of specimen.	Dimensions of net section normal to stress.			Dimensions of diagonal sections.			Angle which diagonal center line makes with line normal to stress.	Area through section along diagonal lines in per cent of section normal to stress.	Yield point.	
	Width.	Thickness.	Area.	Total length.	Thickness.	Area.			Load on specimen.	Load per square inch.
	Inch.	*Inch.*	*Sq. in.*	*Inch.*	*Inch.*	*Sq. in.*	° ′	*Per cent.*	*Pounds.*	*Pounds.*
11	3.06	0.52	1.59	3.06	0.52	1.59	35 56	100	44,000	27,700
12	3.06	.52	1.59	3.44	.52	1.79	41 45	112½	44,200	27,800
13	3.06	.52	1.59	3.68	.52	1.91	44 0	120	48,000	30,200
14	3.06	.52	1.59	4.08	.52	2.12	47 51	133⅓	50,000	31,400
15	3.06	.51	1.56	4.58	.51	2.34	51 45	150	51,700	33,100
16	14.12	.45	6.35	13.91	.45	6.26	16 42	98	204,000	32,600
17	14.12	.44	6.21	14.83	.44	6.52	25 12	105	224,000	36,100
18	14.12	.44	6.21	15.53	.44	6.83	29 46	110	222,000	35,700
19	11.06	.51	5.64	12.45	.51	6.35	41 45 51 10	112½	.....	.....
20	11.06	.51	5.64	14.74	.51	7.52	47 51 56 16	133⅓	160,000	28,400
21	11.06	.51	5.64	16.59	.51	8.46	51 45 59 30	150	177,000	31,400

No. of specimen.	Ultimate strength.		Efficiency of section as compared with solid plate and mill test report.		Remarks.
	Load on specimen.	Load per square inch.	Theoretical based on Massachusetts rules.	Actual from ultimate strength.	
	Pounds.	*Pounds.*	*Per cent.*	*Per cent.*	
11	91,000	57,300	76.5	75.7	Fractured along diagonal lines.
12	94,500	59,400	76.5	78.5	Fractured straight across.
13	96,400	60,500	76.5	80.2	Do.
14	101,000	63,600	76.5	84.0	Do.
15	98,600	63,200	76.5	83.6	Do.
16	324,600	51,900	94.1	81.0	Fractured along diagonal lines.
17	331,200	53,300	94.1	84.6	Fractured straight across.
18	325,400	52,400	94.1	83.1	Do.
19	308,800	54,800	92.1	87.3	Do.
20	309,400	54,900	92.1	87.5	Do.
21	316,500	56,000	92.1	89.5	Do.

TABLE NO. 3.—*Manufacturer's report on material used in these tests.*

Slab number.	Specimen.			Elastic limit per square inch.	Tensile strength.[1]		Elongation in 8 inches.	Contraction area.
	Width.	Thickness.	Area.		Load.	Per square inch.		
	Inch.	*Inch.*	*Sq. in.*		*Pounds.*	*Pounds.*	*Per cent.*	*Per cent.*
9968 G	0.1725	0.380	0.655	36,660	39,100	59,680	30.0	60.3
9968 J	.1915	.447	.856	38,090	50,800	59,340	28.0	60.7
9583 H	.1816	.515	.935	36,160	54,000	57,760	29.5	57.2

Slab number.	Plate.	Chemical properties.			
		C.	M.	S.	P.
9968 G	All plates ¼-inch thick	0.17	0.36	0.023	0.018
9968 J	All plates $\frac{7}{16}$-inch thick	.17	.36	.023	.018
9583 H	All plates ½ inch thick	.18	.44	.030	.012

[1] Firebox, 54,000 pounds per square inch.

Samples of the above withstood the cold and quench bending tests without fracture.

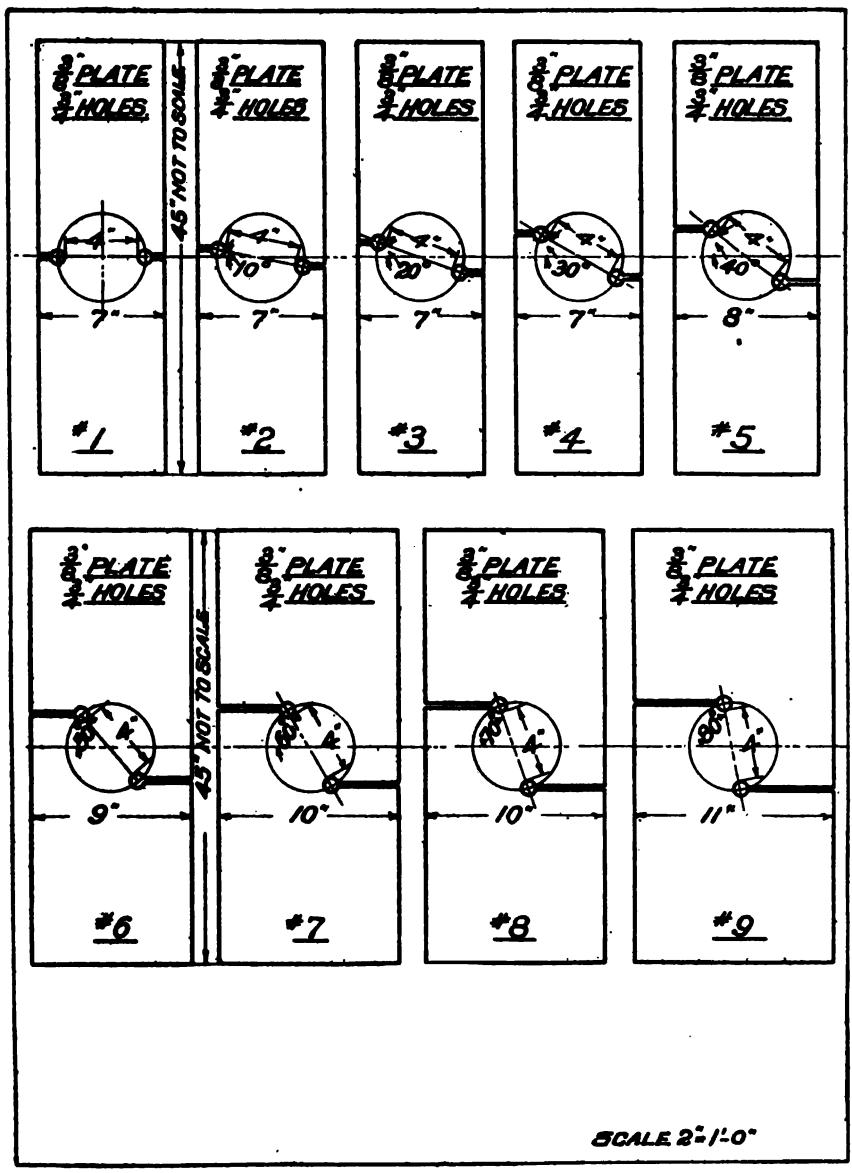


PLATE
HOLES
45° NOT TO SCALE
4"
10°
20°
30°
40°
7"
8"
9"
10"
11"
#1
#2
#3
#4
#5
#6
#7
#8
#9
SCALE 2"=1'-0"

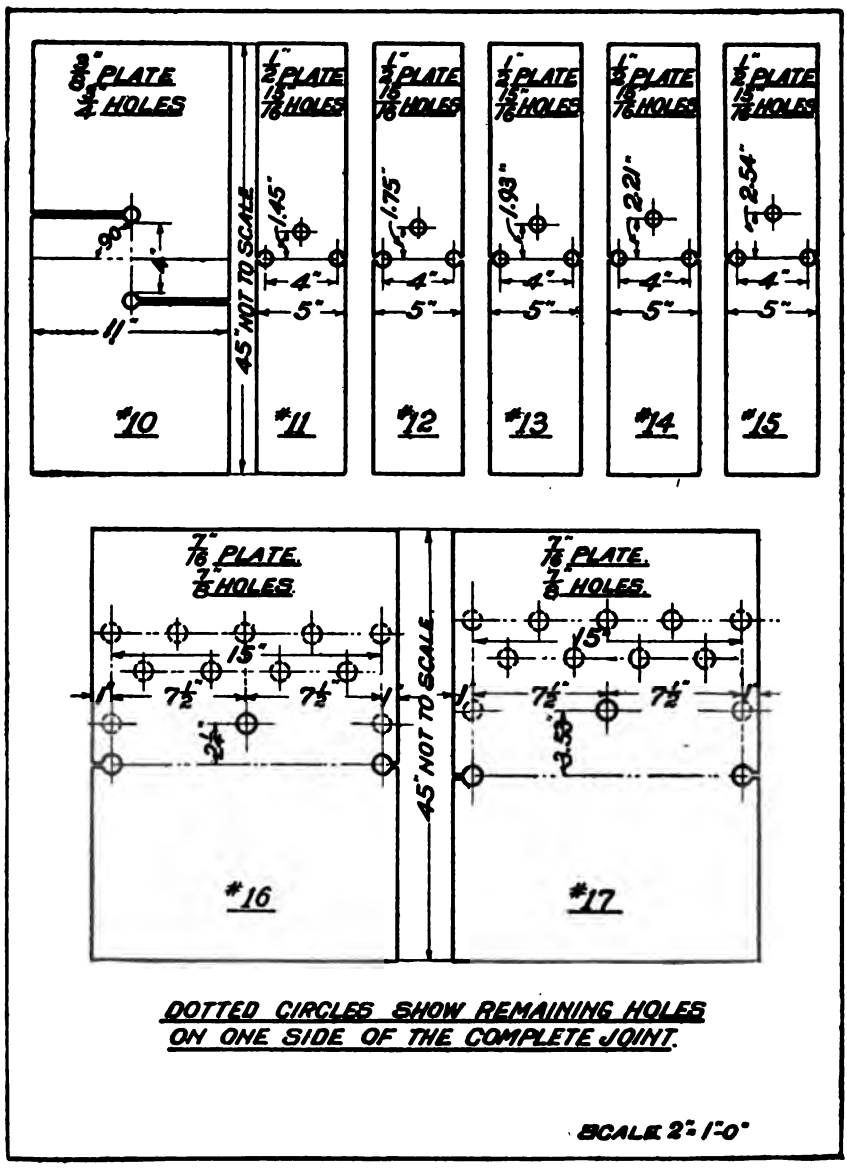


PLATE
HOLES
#10
#11
#12
#13
#14
#15
45° NOT TO SCALE
4"
5"
11"
1.45"
1.75"
1.93"
2.21"
2.54"
PLATE.
HOLES.
15"
7½"
2½"
3.58"
#16
#17
DOTTED CIRCLES SHOW REMAINING HOLES ON ONE SIDE OF THE COMPLETE JOINT.
SCALE 2"= 1'-0"

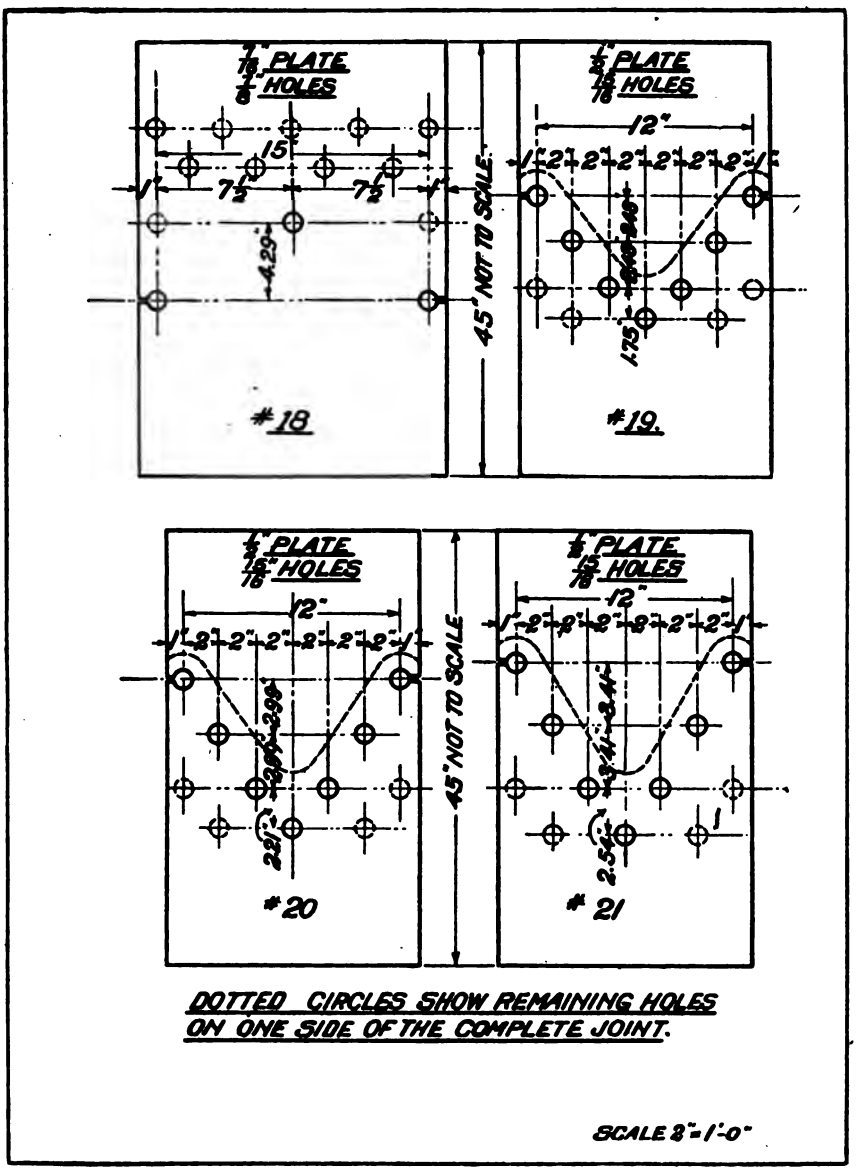
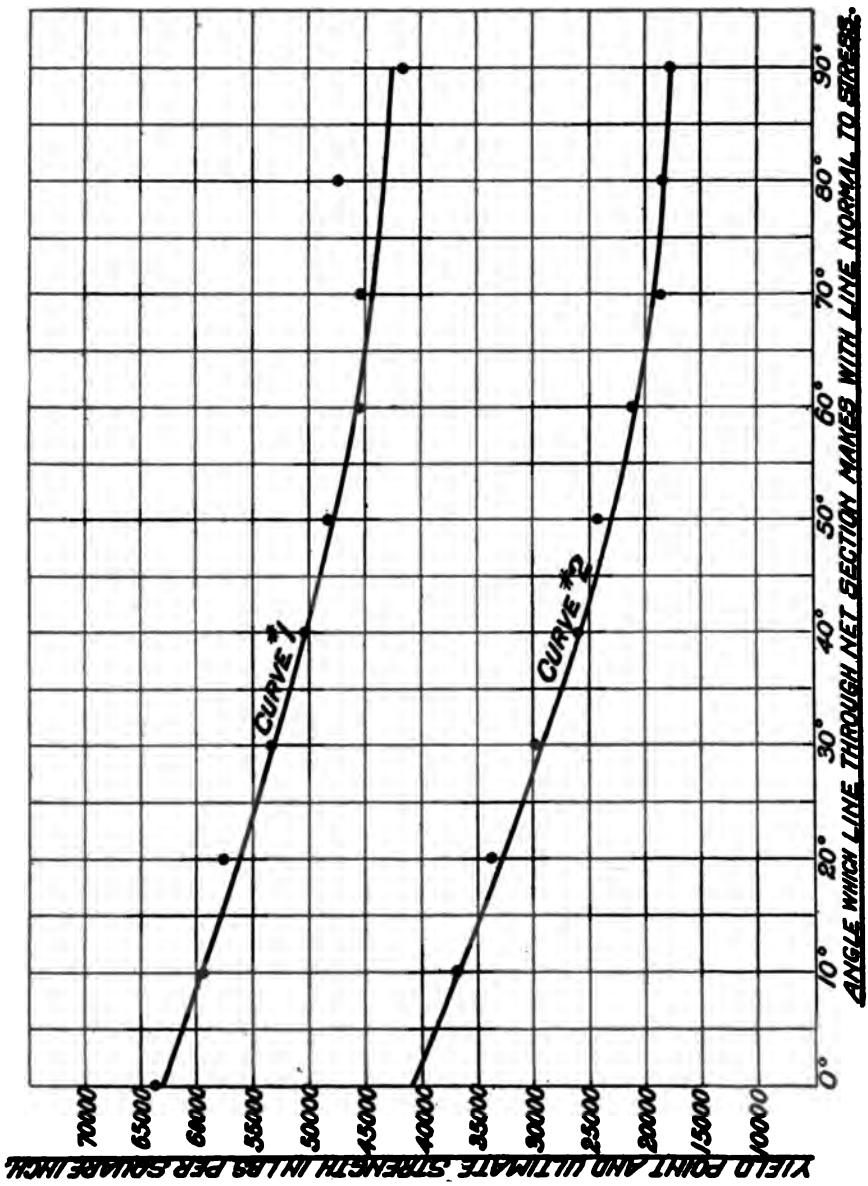
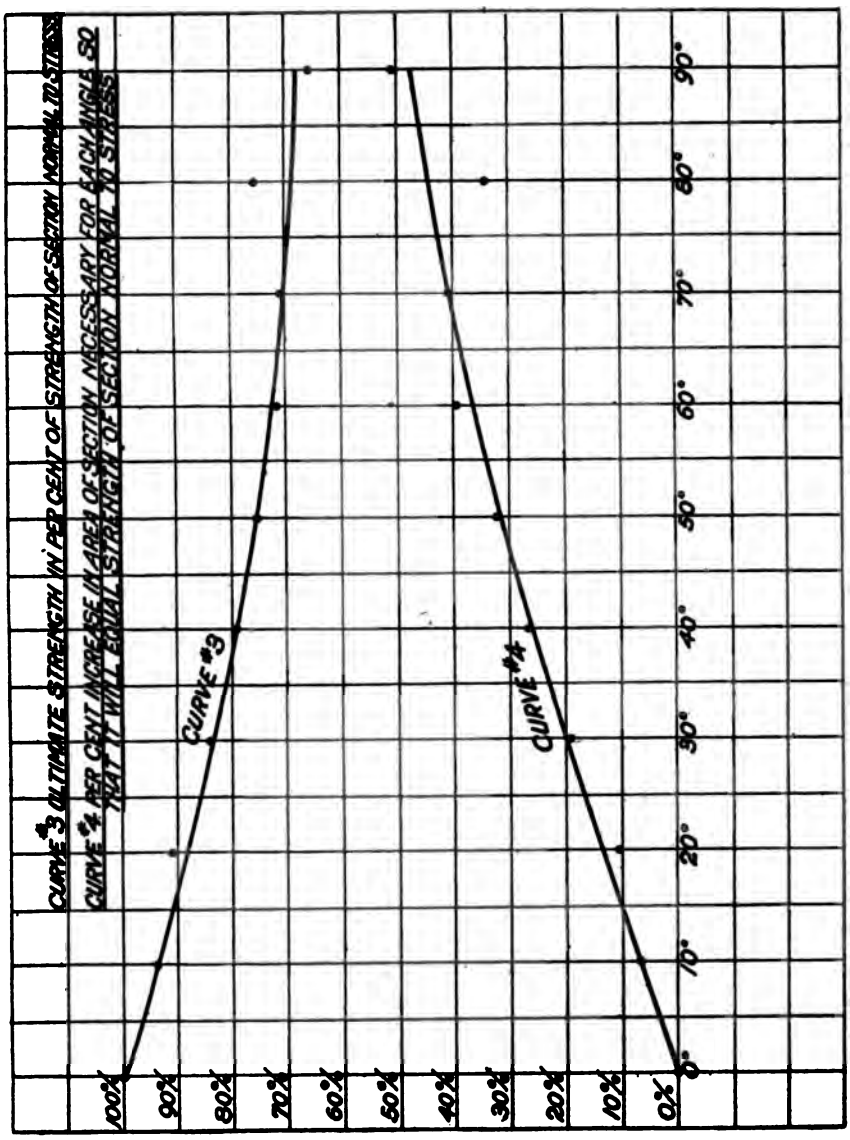


PLATE
HOLES
15"
7½"
7½"
4.29"
#18
45° NOT TO SCALE
PLATE
HOLES
12"
2" 2" 2" 2" 2" 2"
1.75"
#19
PLATE
HOLES
12"
2" 2" 2" 2" 2" 2"
2.99"
2.21"
#20
PLATE
HOLES
12"
2" 2" 2" 2" 2" 2"
2.44"
2.54"
#21
DOTTED CIRCLES SHOW REMAINING HOLES ON ONE SIDE OF THE COMPLETE JOINT.
SCALE 3"=1'-0"

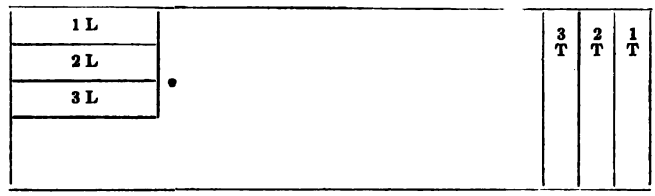

YIELD POINT AND ULTIMATE STRENGTH IN LBS PER SQUARE INCH.
7000
6500
6000
5500
5000
4500
4000
3500
3000
2500
2000
1500
1000
0°
10°
20°
30°
40°
50°
60°
70°
80°
90°
ANGLE WHICH LINE THROUGH NET SECTION MAKES WITH LINE NORMAL TO STRESS.
CURVE #1
CURVE #2


CURVE #3 ULTIMATE STRENGTH W PER CENT OF STRENGTH OF SECTION NORMAL TO STRESS
CURVE #4 PER CENT INCREASE IN AREA OF SECTION NECESSARY FOR EACH ANGLE SO THAT IT WILL EQUAL STRENGTH OF SECTION NORMAL TO STRESS
CURVE #3
CURVE #4
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
0°
10°
20°
30°
40°
50°
60°
70°
80°
90°

COMPARISONS OF LONGITUDINAL AND TRANSVERSE STRENGTHS OF ROLLED FLAT BARS.

LONGITUDINAL AND TRANSVERSE TESTS OF COMMERCIAL ROLLED FLAT BAR STOCK.

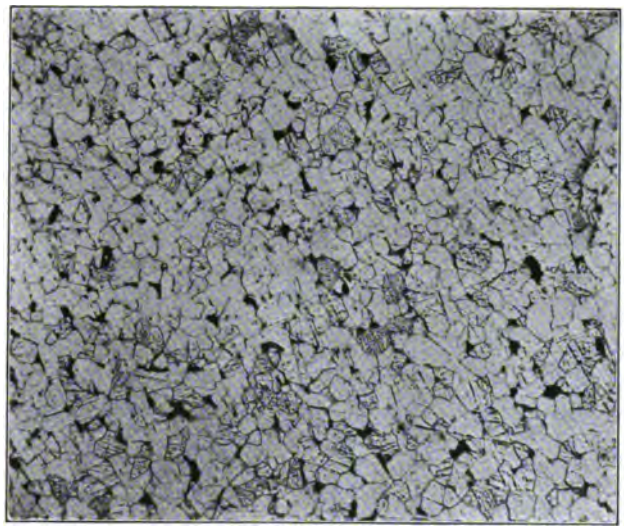
A piece 8 inches long was cut from a 12-foot bar of 1 by 5 inches machinery steel and test pieces were cut longitudinally and transversely, as shown in sketch. These specimens were tested, with the results shown in table below:



Marks.	Yield point per square inch.	Tensile strength per square inch.	Elongation.	Contraction of area.
	Pounds.	*Pounds.*	*Per cent.*	*Per cent.*
M. S. 1 L	40,500	58,500	36.0	67.0
M. S. 2 L	39,000	55,500	36.0	67.0
M. S. 3 L	38,000	56,500	37.0	67.0
M. S. 1 T	37,000	56,500	30.5	49.1
M. S. 2 T	36,000	55,500	31.0	49.1
M. S. 3 T	36,000	56,000	33.5	51.9

The results obtained in the tensile tests confirm previous experiments along this line. The transverse specimens; that is, those taken across the direction of rolling, have practically the same elastic limit and tensile strength as those taken along the direction of rolling, but the former are lower in elongation and contraction of area than the latter.

Microphotographs along and across the direction of rolling are appended. They show the stock to be medium-fine-grained low-carbon steel. The manner in which the slag has been drawn out by rolling is shown in micro No. 2. This micro also reveals a ghost line, in which it will be noted the ferrite grains are quite equiaxed.



NO. 1. (×75.)

NO. 2. (×75.)

ALTERNATING STRESS TESTS OF RAIL METAL.

ALTERNATING STRESS TESTS OF FOUR 1-INCH-DIAMETER BARS TAKEN FROM RAILS.

Length of bars over all, 38 inches.
Diameter of bars, 1 inch.
Deflections measured on two elements (A and B), 180° apart, and over a length of 10 inches.

BAR A.—LABORATORY NUMBER 14645.

Section of head marked C.
O. H. 100-pound rail, heat No. 17360, rolled April, 1910.
From spare rail post. Rail has not been in service.

Heat analysis.

C	0.88
P	.035
S	.037
Mn	.88

Check analysis.

C	0.81
	.92
P	.037
	.040
S	.021
	.030
Mn	.84
	.91

TEST OF BAR.

Speed, 500 revolutions per minute.
Length C. to C. of end bearings, 33 inches.
Diameter of bar, 1 inch.
Loaded over 4 inches at middle.
Fiber stress at start, 10,000 pounds per square inch.
Bar was not very straight; had to be straightened before testing.
Deflection for 10,000 pounds per square inch fiber stress on element A, 0.0081 inch.
Deflection for 10,000 pounds per square inch fiber stress on element B, 0.0083 inch.
The bar was then run for 2 minutes, or 1,000 revolutions, and the measured deflections for 10,000 pounds per square inch fiber stress were: Element A, 0.0082 inch; element B, 0.0083 inch.
The fiber stress was then increased to 20,000 pounds per square inch and deflections measured as follows: Element A, 0.0165 inch; element B, .0162 inch.
The bar was run two minutes, or 1,000 rotations, at this fiber stress of 20,000 pounds per square inch, after which deflections were measured as follows: Element A, 0.0165 inch; element B, 0.0162 inch.

The fiber stress was then increased to 30,000 pounds per square inch and deflections measured as follows: Element A, 0.0246 inch; element B, 0.0244 inch.

The bar then rested over night.

The bar was then run two minutes, or 1,000 rotations, at this fiber stress of 30,000 pounds per square inch, after which deflections were measured as follows: Element A, 0.0244 inch; element B, 0.0244 inch.

The fiber stress was then increased to 40,000 pounds per square inch and deflections measured as follows: Element A, 0.0328 inch; element B, 0.0326 inch.

The bar was run two minutes, or 1,000 rotations, at this fiber stress of 40,000 pounds per square inch, after which deflections were measured as follows: Element A, 0.0327 inch; element B, 0.0325 inch.

After 7,000 rotations the bar was allowed to rest, as it was running hot. Water was then run on bar to keep it cool.

At 71,200 rotations the bar rested over night.

After 200,000 revolutions, and at a fiber stress of 40,000 pounds per square inch, deflections were measured as follows: Element A, 0.0323 inch; element B, 0.0320 inch.

After 200,000 rotations the bar rested one week.

After 200,000 rotations, after resting one week, and at a fiber stress of 40,000 pounds per square inch, the deflections were as follows: Element A, 0.0322 inch; element B, 0.0322 inch.

At 371,800 rotations the bar rested eight days.

At 457,000 rotations the bar ruptured at the south edge of south middle bearing, outside of the middle bearings.

BAR B.—45206 A.

Laid November, 1912. Removed February 14, 1914.

TEST OF BAR.

Speed, 500 revolutions per minute.

Length C. to C. of end bearings, 33 inches.

Diameter of bar, 1 inch.

Loaded over 4 inches at middle.

Fiber stress to start, 10,000 pounds per square inch.

Bar not very straight; had to be straightened before testing.

Deflection for 10,000 pounds per square inch fiber stress on element A, 0.0081 inch.

Deflection for 10,000 pounds per square inch fiber stress on element B, 0.0080 inch.

The bar was then run for two minutes, or 1,000 revolutions, and the measured deflections for 10,000 pounds per square inch fiber stress were: Element A, 0.0081 inch; element B, 0.0080 inch.

The fiber stress was then increased to 20,000 pounds per square inch, and deflections measured as follows: Element A, 0.0155 inch; element B, 0.0155 inch.

The bar was then run two minutes, or 1,000 rotations at this fiber stress of 20,000 pounds per square inch, after which deflections were measured as follows: Element A, 0.0159 inch; element B, 0.0156 inch.

The fiber stress was then increased to 30,000 pounds per square inch and deflections measured as follows: Element A, 0.0246; element B, 0.0238 inch.

The bar was then run two minutes, or 1,000 rotations at this fiber stress of 30,000 pounds per square inch, after which deflections were measured as follows: Element A, 0.0239 inch; element B, 0.0231 inch.

The fiber stress was then increased to 40,000 pounds per square inch and deflections measured as follows: Element A, 0.0311 inch; element B, 0.0308 inch.

The bar was then run two minutes, or 1,000 rotations at this fiber stress of 40,000 pounds per square inch, after which deflections were measured as follows: Element A, 0.0315 inch; element B, 0.0314 inch.

At 7,000 rotations the bar was running hot, so was allowed to rest overnight. Water was run on bar to keep it cool.

At 71,200 rotations the bar rested.

After 200,000 revolutions, and at a fiber stress of 40,000 pounds per square inch, deflections were measured as follows: Element A, 0.0314 inch; element B, 0.0319 inch.

At 200,000 rotations the bar rested one week, after which time the deflections measured were as follows: Element A, 0.0317 inch; element B, 0.0316 inch.

At 371,800 rotations the bar rested one week.

At 457,000 rotations the bar rested overnight.

At 628,100 rotations the bar rested overnight.

At 707,500 rotations the bar rested three days.

At 822,700 rotations the bar rested overnight.

At 993,440 rotations the bar ruptured at south edge of north middle bearing—between the middle bearings.

BAR C.—WRECK.

From head of rail, 75-pound section.

Gauge side of head from section marked (1).

TEST OF BAR.

Speed, 500 revolutions per minute.

Length, C. to C. of end bearings, 33 inches.

Diameter of bar, 1 inch.

Loaded over 4 inches at middle.

Fiber stress to start, 10,000 pounds per square inch.

Bar not very straight; had to be straightened before testing.

Deflection for 10,000 pounds per square inch fiber stress on element A, 0.0080 inch.

Deflection for 10,000 pounds per square inch fiber stress on element B, 0.0081 inch.

The bar was then run for two minutes, or 1,000 revolutions, and the measured deflections for 10,000 pounds per square inch fiber stress were: Element A, 0.0080 inch; element B, 0.0081 inch.

The fiber stress was then increased to 20,000 pounds per square inch and deflections measured as follows: Element A, 0.0162 inch; element B, 0.0161 inch.

The bar then rested three days, after which it was run two minutes, or 1,000 rotations at this fiber stress of 20,000 pounds per square inch. The deflections then measured as follows: Element A, 0.0163 inch; element B, 0.0161 inch.

The fiber stress was then increased to 30,000 pounds per square inch and deflections measured as follows: Element A, 0.0239 inch; element B, 0.0239 inch.

The bar was then run for two minutes, or 1,000 revolutions, and the measured deflections for 30,000 pounds per square inch fiber stress were: Element A, 0.0244 inch; element B, 0.0236 inch.

The fiber stress was then increased to 40,000 pounds per square inch and deflections measured as follows: Element A, 0.0324 inch; element B, 0.0320 inch.

The bar was then run two minutes, or 1,000 revolutions, and the measured deflections for 40,000 pounds per square inch fiber stress were: Element A, 0.0324 inch; element B, 0.0322 inch.

Water was then run on bar to keep it cool.

At 75,000 rotations the bar rested two weeks.

At 88,100 rotations the bar rested overnight.

At 200,000 rotations the bar rested 18 days, after which and at a fiber stress of 40,000 pounds per square inch, the deflections were as follows: Element A, 0.0318 inch; element B, 0.0321 inch.

The bar then rested one week.

At 261,600 rotations the bar rested three days.

At 610,900 rotations the bar rested two days.

At 816,600 rotations the bar rested ten days.

At 926,700 rotations the bar ruptured at north edge of south middle bearing—between the middle bearings.

BAR D.—WRECK.

From head of rail, 75-pound section.

Outside of head from section marked (1).

TEST OF BAR.

Speed, 500 revolutions per minute.

Length, center to center of end bearings, 33 inches.

Diameter of bar, 1 inch.

Loaded over 4 inches at middle.

Fiber stress to start, 10,000 pounds per square inch.

Bar not very straight; had to be straightened before testing.

Deflection for 10,000 pounds per square inch fiber stress on element A, 0.0081 inch.

Deflection for 10,000 pounds per square inch fiber stress on element B, 0.0082 inch.

The bar was then run for two minutes, or 1,000 revolutions, and the measured deflections for 10,000 pounds per square inch fiber stress were: Element A, 0.0080 inch; element B, 0.0080 inch.

The fiber stress was then increased to 20,000 pounds per square inch and the deflections measured as follows: Element A, 0.0160 inch; element B, 0.0159 inch.

The bar was run two minutes, or 1,000 rotations at this fiber stress of 20,000 pounds per square inch, after which deflections were measured as follows: Element A, 0.0161 inch; element B, 0.0161 inch.

The fiber stress was then increased to 30,000 pounds per square inch and the deflections measured as follows: Element A, 0.0230 inch; element B, 0.0239 inch.

The bar was run two minutes, or 1,000 rotations at this fiber stress of 30,000 pounds per square inch, after which deflections were measused as follows: Element A, 0.0238 inch; element B, 0.0239 inch.

The fiber stress was then increased to 40,000 pounds per square inch and the deflections measured as follows: Element A, 0.0313 inch; element B, 0.0313 inch.

The bar was run two minutes, or 1,000 rotations at this fiber stress of 40,000 pounds per square inch, after which deflections were measured as follows: Element A, 0.0308 inch; element B, 0.0316 inch.

Water was then run on the bar to keep it cool. The bar was allowed to rest two weeks after it reached 75,000 rotations.

At 83,600 rotations the screw that held up the center bearing worked down and scored the bar at the middle of length, or between the middle bearings. The score was smoothed off and test continued.

At 88,100 rotations the bar rested over night. At 200,000 rotations the bar rested 18 days.

At 200,000 rotations, and after resting and at a fiber stress of 40,000 pounds per square inch, the deflections measured as follows: Element A, 0.0317 inch; element B, 0.0318 inch.

At 200,000 rotations, and after measuring deflections, the bar rested one week.

At 261,600 rotations the bar rested three days.

At 262,000 rotations the bar ruptured at score mark between the middle bearings or 1⅛ inches north of the north edge of south middle bearing.

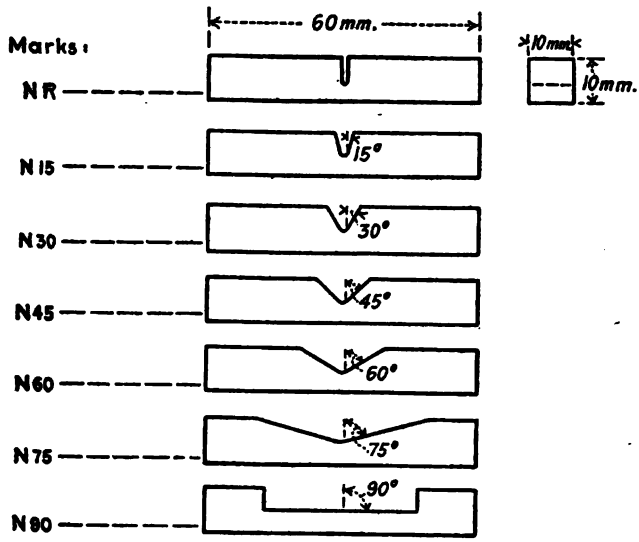
In all cases, whenever the bar rested the load was relieved.

CHARPY IMPACT TESTS.

EFFECT OF THE SHAPE OF THE NOTCH ON CHARPY IMPACT TEST RESULTS.

With a view to determining the effect of the shape of the notch on the results of Charpy impact tests, the following experiment was carried out.

The Charpy impact machine (see figs. 1 and 2) is one of 30 kilogram-meters, or 217.6 foot-pounds capacity. The standard transverse specimen for this machine is 10 by 10 by 60 millimeters with a notch



-Charpy Test Specimens.

Fig. 3.

1 millimeter wide by 5 millimeters deep midway along one side. This is a difficult piece to machine from hard steels on account of the narrowness of the notch. If a suitably shaped test specimen could be found which would give comparative results with the standard and would be at the same time easier to machine, it would perhaps be advantageous to adopt it. Figure 3 shows dimenions of specimens and shapes of notches investigated.

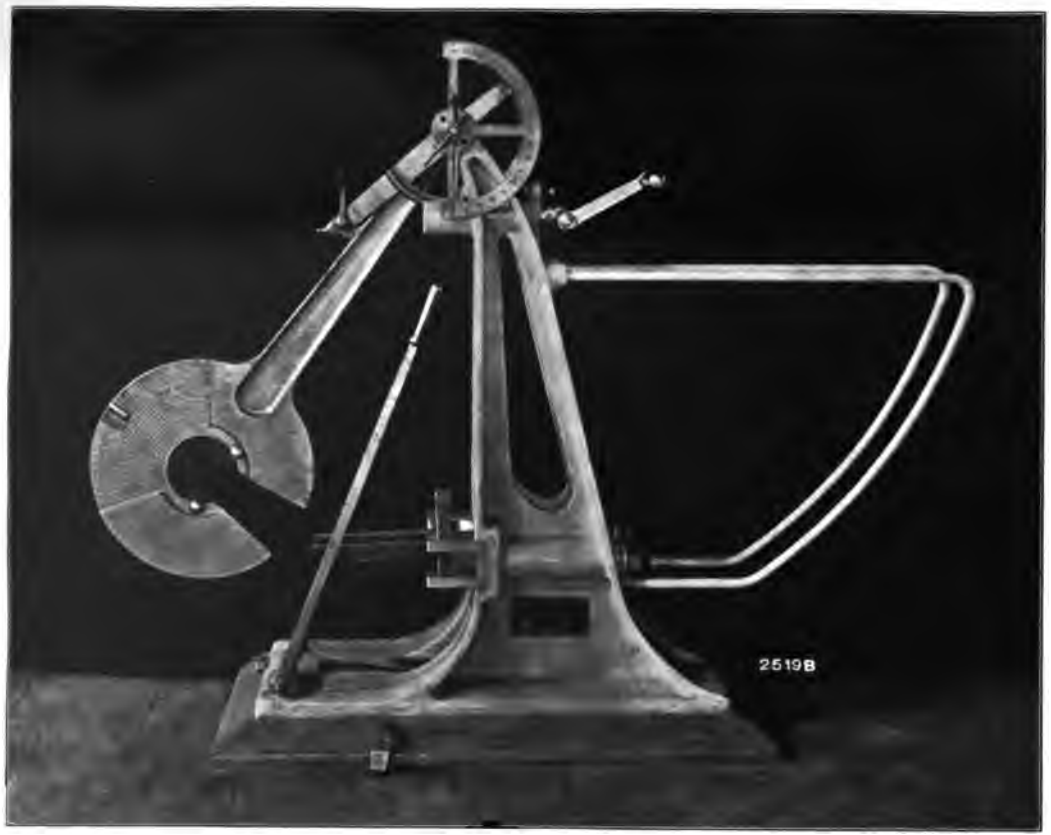


FIG. NO. 1.

FIG. NO. 2.

A piece of hot-rolled machinery steel ½ by 3 by 28 inches was selected from stock and cut into lengths 3 inches long. The analysis of this material was as follows:

	Per cent.
Carbon	0.134
Manganese	.39
Silicon	.015
Sulphur	.021
Phosphorus	.017

The pieces when cut to length were annealed by heating slowly to 875° C. They were held at this temperature 10 minutes and allowed to cool slowly in the furnace over a period of five or six hours to room temperature.

After the annealing operation a small section was polished and etched for microscopic examination. The structure shown in figure 5 consisted of fine-grained ferrite and uniformly distributed islands of pearlite and is quite satisfactory for the heat treatment given. From each of the annealed pieces six transverse Charpy test specimens were machined, as indicated in figure 3. The specimens were all taken out along the original direction of rolling of the bar. These specimens were tested in the Charpy machine in the usual manner, and the results are tabulated herewith.

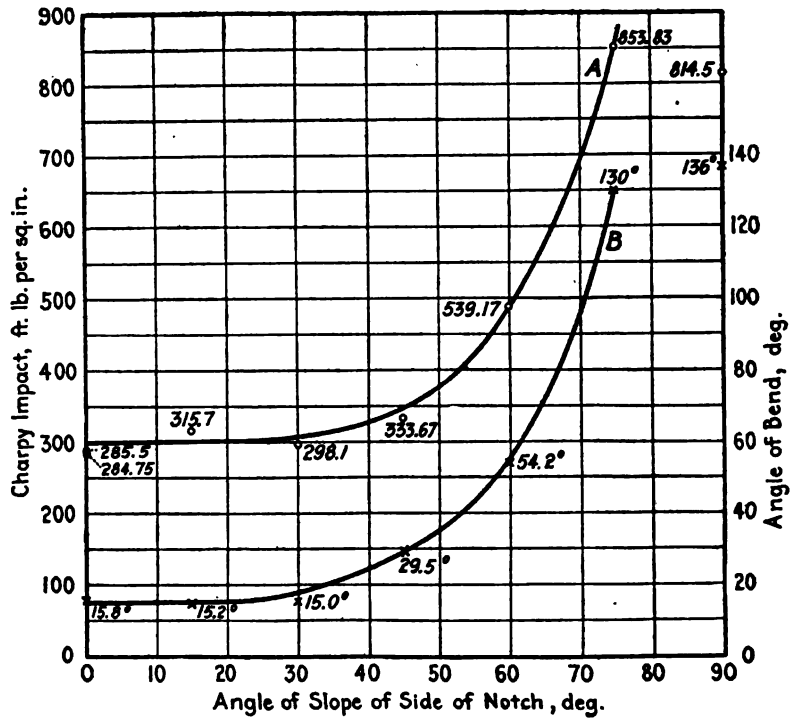
Specimen number.	Foot-pounds per square inch.			Angle of bend.	Brinell hardness number, average of 3.	Remarks.
	Maximum.	Minimum.	Average of 6 specimens.			
N R	304.0	266.5	284.75	15.8°	79.1	Regular specimen.
N 15°	345.9	283.0	[1] 315.70	15.2°	77.5	
N 30°	322.5	284.0	298.10	15.0°	80.9	
N 45°	382.0	304.0	333.67	29.5°	80.0	
N 60°	571.0	516.0	539.17	54.2°	79.8	Fractured but did not separate.
N 75°	890.0	818.0	853.83	130.0°	78.4	Fractured halfway through. Did not separate.
N 90°	830.0	806.0	814.5	136.0°	78.4	Bent. Did not fracture.

[1] Average of five specimens.

An examination of the tabulated data will show that the widening out of the notch did not greatly affect the average figures for resistance to shock until the slope of the side of the notch exceeded 45 degrees. The figures for resistance to shock of the 15-degree specimens are somewhat higher than those for either the regular or the 30-degree specimens. This difference, however, is hardly greater than may be accounted for by experimental error. It will be noticed in this connection that the Brinell hardness values of these specimens is the lowest of any. In general, the lower the hardness is the greater is the resistance to shock. Figures for the angle at the bend have been recorded, though these are somewhat uncertain, owing to the difficulty of satisfactorily placing together the two broken ends of the specimen. These figures, however, agree fairly closely with those for the shock strength.

The two curves shown herewith summarize the results obtained in this experiment so that they may be seen at a glance. Both curves have the same abscissa, namely, the angle of slope of the side of the

notch, while the ordinates for curve A are foot-pounds per square inch, and for curve B are degrees angle of bend. From these curves it may be stated that resistance to shock and angle of bend are not affected in Charpy impact tests by cutting away the side of the notch up to as much as 30 degrees. By increasing the slope of the side of the notch from 30 degrees to nearly 90 degrees, or at least to 75 degrees, the resistance to shock and the angle of bend are rapidly increased.



—Effect of Shape of Notch on Charpy Impact Tests.

Fig. 4.

The results of the tests of the specimens with a 90-degree slope, that is, the specimens with no notch whatever, do not fall on the curve, for the point of fracture was not located and the pieces did not fracture.

SUMMARY.

It has been shown that the side of the notch of the regular Charpy impacy test specimen may be cut away as much as 30 degrees from the vertical without materially affecting the experimental results.

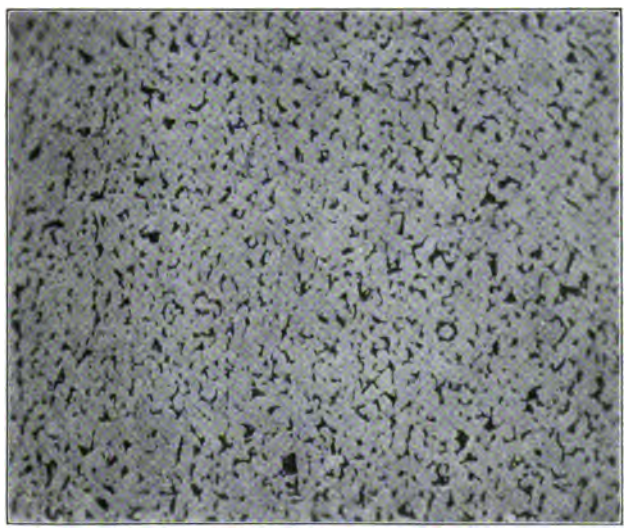


FIG. 5. (×75.)

EXPERIMENTS ON SIMPLE OVERSTRAIN.

THE EFFECT OF THE OVERSTRAIN ACCOMPANYING TENSILE RUPTURE ON THE TENSILE AND COMPRESSIVE CHARACTERISTICS OF STEEL.

TERMINOLOGY.

The term "overstrain" includes all strains beyond the yield point, hence any strain which is in part plastic. Overstrain can result only from "cold working," such as cold-rolling, cold-drawing, or physical testing beyond the yield point.

A tensile test specimen from homogeneous material, when tested to rupture, presents a general plastic elongation and contraction of area, and a local excessive elongation and contraction of area termed "necking down," at and on either side of the plane of rupture. As a rule, therefore, there is a local overstrain of one magnitude at and near the plane of rupture, and a general overstrain of lesser magnitude, due to the "maximum unit stress" which appears on the stress-strain diagram. This latter overstrain will be designated by the term "rupture strain."

In this experiment we are concerned with static tensile rupture strain and its effect on the tensile and compressive characteristics of steel.

PROGRAM.

The plan of the experiment was to determine accurately by the usual test specimens the tensile and compressive characteristics of a bar of steel. From the remainder of the bar was to be taken a specimen of such dimensions that after tensile rupture, further suitable tensile and compressive specimens might be cut from the broken ends. The tensile and compressive characteristics of the "rupture-strained" metal were to be obtained by test of these specimens.

In order to carry out this program a commercial unannealed hot-rolled bar of 3½ per cent nickel steel $1\frac{7}{16}$ inch diameter by 8 feet long was selected. This bar was of approximately the following composition:

	Per cent.
Carbon	0.45
Manganese	.50
Silicon	.10
Sulphur	.04
Phosphorus	.04
Nickel	3.25

From this bar there were prepared two tension test specimens of a 10-inch gauge length, and two compression test specimens 1 inch in diameter by 6 inches long, with 5-inch gauge lengths. These four bars were tested and the stress-strain diagrams accurately determined. The remainder of the original 8-foot bar was made up into a tensile

specimen about 5 feet long. This specimen was tested to rupture in tension, and its stress-strain diagram determined. The broken ends of this bar consist then of rupture-strained metal, and from these ends tensile and compression pieces were machined and tested.

APPARATUS.

All tests were carried out in the arsenal's 800,000-pound Emery hydraulic-principle testing machine. The extensometers used were of the precision micrometer type, equipped with electric contact device, and by this means readings to one ten-thousandth of an inch could be made. Photograph No. 1 shows the extensometer assembly for a tensile test.

DESCRIPTION OF TESTS.

In carrying out the tests the extensometer was attached to the specimen and a zero reading obtained with a load of 1,000 pounds per square inch initial stress. The load was then applied in increments of 5,000 pounds unit stress to a point well below the elastic limit, when the increments of load were decreased to 1,000 pounds. Measurements of lengthening or shortening were continued with the precision micrometer up to its limit of reading, which was two-tenths of an inch. Beyond this point, deformation was measured by means of a vernier rule, which is shown in photograph No. 2.

When tensile specimen No. 5 had been tested, it was noted that it had reduced in diameter unevenly along its length. There appeared to be minor necking down at several points other than the point of fracture, though this reduction was not more than ten one-thousandths of an inch in any case. This meant, however, that the metal at these points was cold worked more than at other parts of the bar. Attention is called to this condition in connection with the behavior of some of the overstrained compression specimens to be described later on. The period of rest allowed before the overstrained specimens were tested varied considerably, but in no case was this period less than a week. Specimens 6 and 7 which were tested in tension after overstraining were allowed to rest one week. Specimens 8, 9, 10, and 11, which were tested in compression after overstraining were allowed to rest seven weeks, while specimen 12, which was tested in compression after overstraining, was allowed to rest 16 weeks. This specimen was not tested compressively to destruction, but only to a unit stress of 60,000 pounds. It was then rested a week, made into a tensile specimen, 12T, and tested in tension to destruction. This specimen had then been subjected to reversing overstrain.

RESULTS.

Four tables, summarizing the results of these tests, are given herewith. The data and stress-strain diagrams for each test are appended.

DISCUSSION.

Consideration of these tables and the appended stress-strain diagrams discloses that the values for elastic or proportionality limit for the rupture-strained metal are rather indefinite. The values for yield point also, in the case of the rupture-strained specimens, is only

approximate. These values, however, are sufficiently distinctive and pronounced so that some definite conclusions as to the effects of rupture strain can be reached. One point to be noted is that in the original condition, this material has practically the same unit stress values for elastic limit, yield point, and maximum strength in tension as it has in compression. The results of the compression tests of the rupture-strained material seemed to vary with the size of the specimens; that is, the smaller specimens showed lower unit stress values, possibly owing to too low values of the ratio, diameter over length. Specimens of a length of 2½ to 4 diameters might give higher as well as more uniform values. Also the variation in the amount of cold work throughout the length of original specimen No. 5 may have influenced somewhat the values obtained for the rupture-strained specimens. These various points are being investigated further, but these results are presented as being of interest.

CONCLUSIONS.

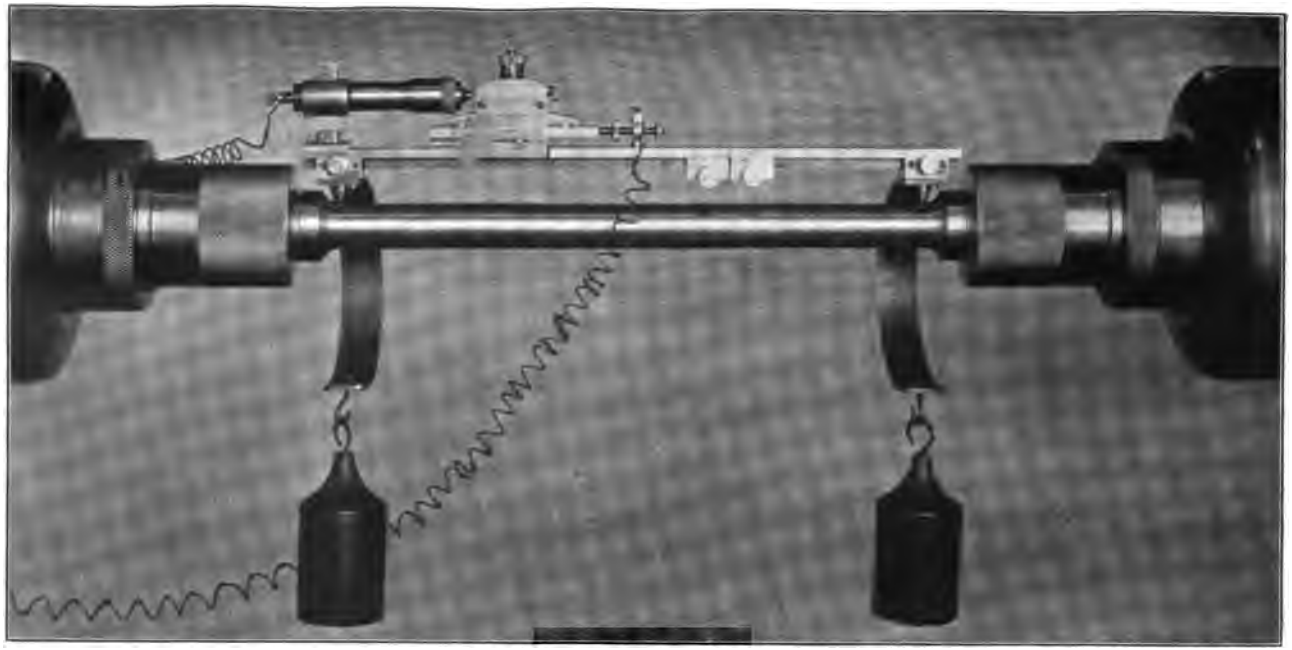
From the results herein reported it is believed the following conclusions can be drawn:

(1) When 3½ per cent nickel steel is stressed to its maximum unit strength in tension (unit stress being referred to the original diameter of the piece), rested a week and again tested in tension, (*a*) the yield point, though indefinite, is raised to or above the previous maximum strength, (*b*) the new maximum strength is raised considerably above its original value.

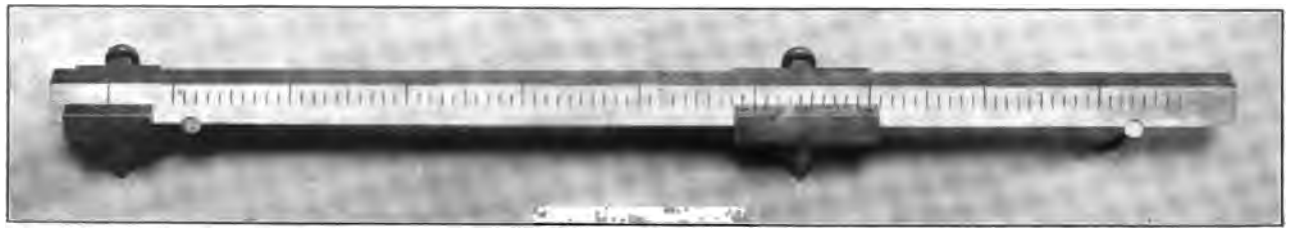
(2) When 3½ per cent nickel steel is stressed to its maximum unit strength in tension (unit stress being referred to the original diameter of the piece), rested seven weeks or longer and then tested in compression, (*a*) the yield point and maximum strength will not be materially increased and will possibly both be decreased in comparison with the original compressive characteristics of the material. The exact physical properties obtained will depend to some extent on (*a*) the amount of cold working of the metal during the first rupture strain and (*b*) on the proportions of the test specimen.

TABLE 1.—*Tensile tests of original material.*

Specimen No.	Condition of material.	Size of specimens.			Proportionality limit (pounds per square inch).	Yield point (pounds per square inch).	Maximum strength (pounds per square inch).	Elongation.	Contraction of area.	Ratio diameter over gauge length.
		Length.	Diameter.	Gauge length.						
		Inches.	*Inches.*	*Inches.*				*Per cent.*	*P. ct.*	*P. ct.*
1...	Original.....	10+	1.009	10	51,000 ? 56,000 ?	59,000	112,375	In 10 inches, 16.4.	47.7	10.09
2...	.....do.....	10+	1.009	10	55,000 ?	59,000	111,500	In 10 inches, 15.9.	47.7	10.09
3...	.....do.....	56+	1.009	45	57,000 ?	60,000	111,000	In 45 inches, 10.9.	47.7	2.24



PHOTOGRAPH NO. 1.



PHOTOGRAPH NO. 2.

TABLE 2.—*Tensile tests of overstrained material.*

Specimen No.	Condition of material.	Size of specimens.			Proportionality limit (pounds per square inch).	Yield point (pounds per square inch).	Maximum strength (pounds per square inch).	Elongation.	Contraction of area.	Ratio diameter over gauge length.
		Length.	Diameter.	Gauge length.						
		Inches.	*Inch.*	*Inches.*				*Per cent.*	*P. ct.*	*P. ct*
6...	Overstrain in tension.	5+	0.564	5	Indefinite.	[1]120,000	124,000	In 5 inches, 5.	40.8	11.27
7...	.....do.....	5+	.564	5	Indefinite.	[1]117,000	121,000	In 5 inches, 4.8.	41.9	11.27
12T	Overstrained in tension, then in compression.	2+	.505	2	Indefinite.	[1]120,000	124,000	In 2 inches, 12.	40.3	25.2

[1] Approximately.

Specimens Nos. 6 and 7 rested 1 week.

Specimen No. 12 T rested 17 weeks after tensile overstrain, 1 week after compressive overstrain.

TABLE 3.—*Compressive tests of original material.*

Specimen No.	Condition of material.	Size of specimens.			Proportionality limit (pounds per square inch).	Yield point (pounds per square inch).	Maximum strength (pounds per square inch).	Ratio diameter over length.
		Length.	Diameter.	Gauge length.				
		Inches.	*Inches.*	*Inches.*				*Per cent.*
3.....	Original...	6	1	5	57,000 ?	60,000	108,790	16.67
4.....	...do.....	6	1	5	51,000 ?	60,000	109,300	16.67

TABLE 4.—*Compressive tests of overstrained material.*

Specimen No.	Condition of material.	Size of specimens.			Proportionality limit (pounds per square inch).	Yield point (pounds per square inch).	Maximum strength (pounds per square inch).	Ratio diameter over length.	Period of rest.
		Length.	Diameter.	Gauge length.					
		Inches.	*Inch.*	*Inches.*				*P. ct.*	
8...	Overstrained in tension.	4¾	0.874	3.0	39,000 ?	60,000 ?	111,165	20.0	Seven weeks.
9...	.....do.....	4¾	.874	2.5	45,000 ?	62,000 ?	113,165	20.0	Do.
10...	.....do.....	4.0	.564	3	28,000 ?	35,000 ?	90,400	14.1	Do.
11...	.....do.....	4.0	.564	3	25,000 ?	33,000 ?	91,200	14.1	Do.
12...	...do.....	5.25	.785	4	[1] 25,000 to 35,000	40,000 ?	.....	14.9	Sixteen weeks.

[1] Indefinite.

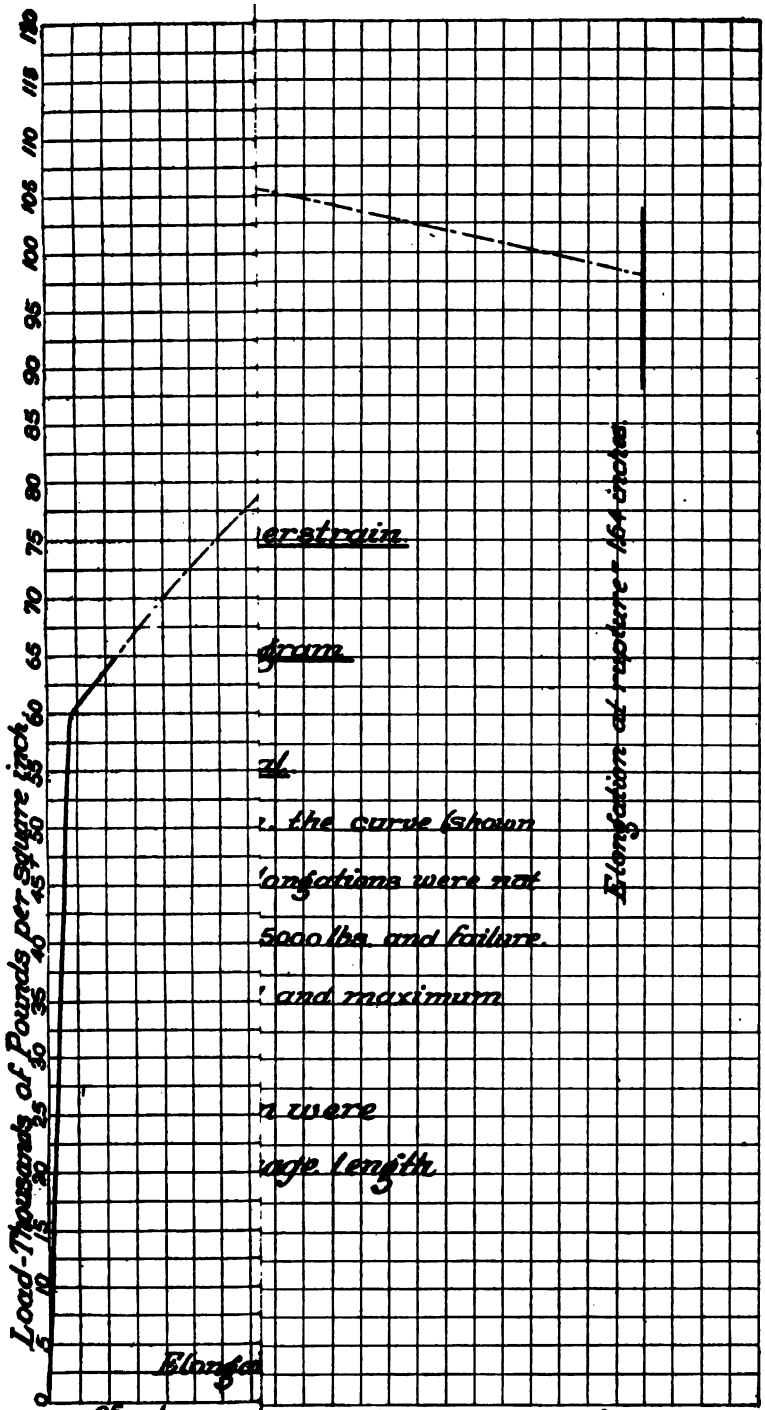
TENSION TEST, SPECIMEN NO. 1.

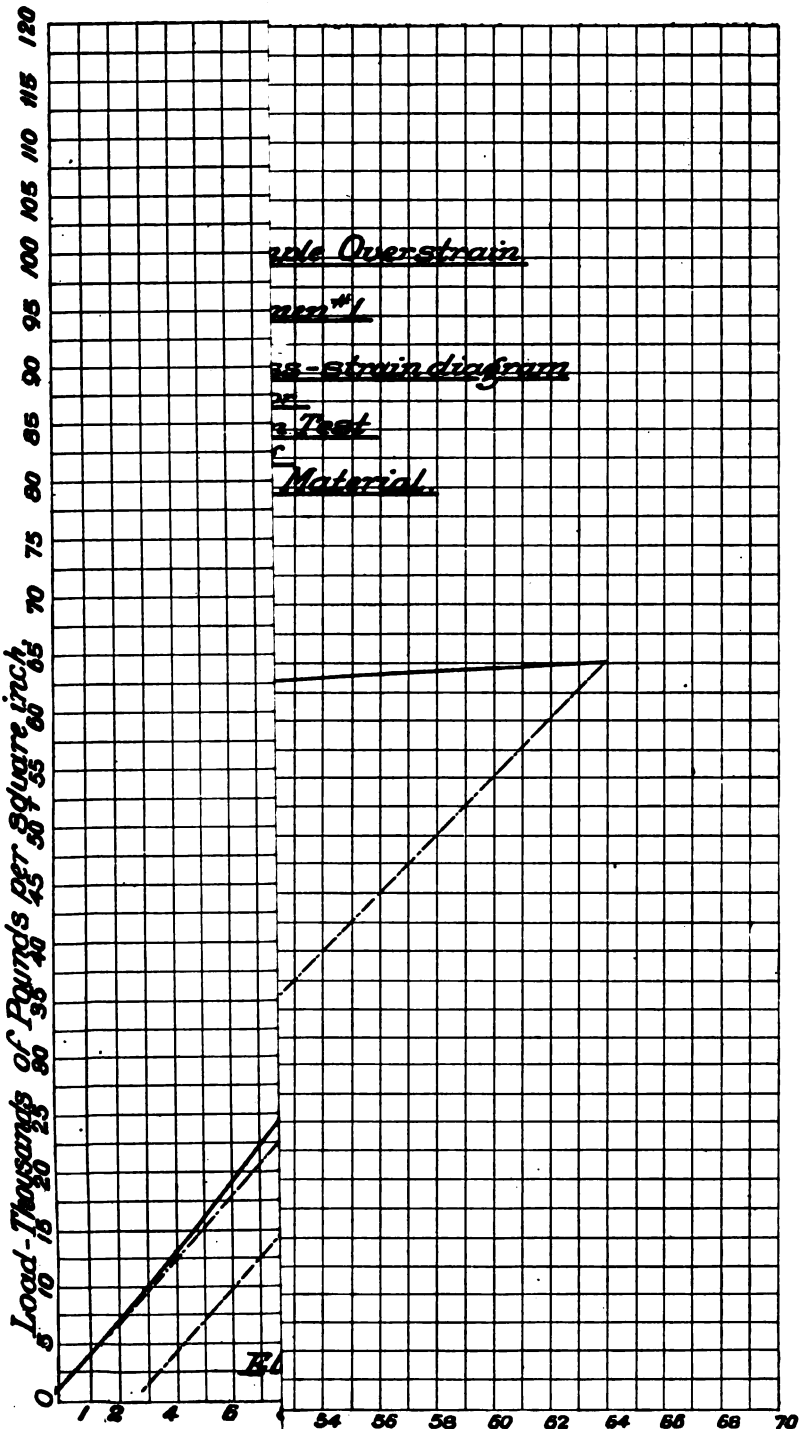
Original condition.
Diameter, 1.009 inches.
Sectional area, 0.80 square inch.
Gauged length, 10 inches.

Applied loads.		In gauged length.		Applied loads.		In gauged length.	
Total pounds.	Pounds per square inch.	Elongation (inch).	Set (inch).	Total pounds.	Pounds per square inch.	Elongation (inch).	Set (inch).
800	1,000	0	0		54,000	0.0193	.....
	5,000	.0014	0		55,000	.0197	.....
	10,000	.0031	.....		56,000	.0201	.....
	15,000	.0048	.....		57,000	.0206	.....
	20,000	.0064	.....		58,000	.0212	.....
	25,000	.0080	.....		[2] 59,000	.0219	.....
	30,000	.0099	.....			.0227	
	35,000	.0117	.....		60,000	.0242	+0.0029
	[1] 40,000	.0136	−.0006		61,000	.0305	.....
	45,000	.0158	.....		62,000	.0427	.....
	50,000	.0176	−.0002		63,000	.0492	.....
	51,000	.0179	.....		64,000	.0560	.....
	52,000	.0184	.....		65,000	.0637	.0386
	53,000	.0188	.....	89,900	[3] 112,375	.....	.....

[1] Micrometer reset at zero. Elongation at 40,000 pounds = 0.0138 inch.
[2] Yield point.
[3] Tensile strength.

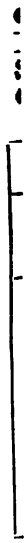
Elongation after fracture, 1.64 inches = 16.4 per cent.
Elongation of inch sections, .09, .12, .13, .13, .44*, .22, .14, .14, .14, .09.
Diameter at fracture, 0.73 inch.
Sectional area at fracture, 0.418 square inch.
Contraction of area, 47.7 per cent.
Position of fracture, 5.50 inches from the neck.
Appearance of fracture: Silky.


Load-Thousands of Pounds per Square Inch
0
5
10
15
20
25
30
35
40
45
50
55
60
65
70
75
80
85
90
95
100
105
110
115
120
.05
.1
1.4
1.5
1.6
Elongation at rupture=.164 inches
erstrain
gram
H
. the curve shown
'ongations were not
5000 lbs. and failure
' and maximum
n were
age length
Elongation


Load-Thousands of Pounds per Square inch.
0 5 10 15 20 25 30 35 40 45 50 55 60 65 70 75 80 85 90 95 100 105 110 115 120
1 2 4 6
54 56 58 60 62 64 66 68 70
ple Overstrain.
menth l
ss-strain diagram
Test
Material.

42461°—17. (To face pag

10



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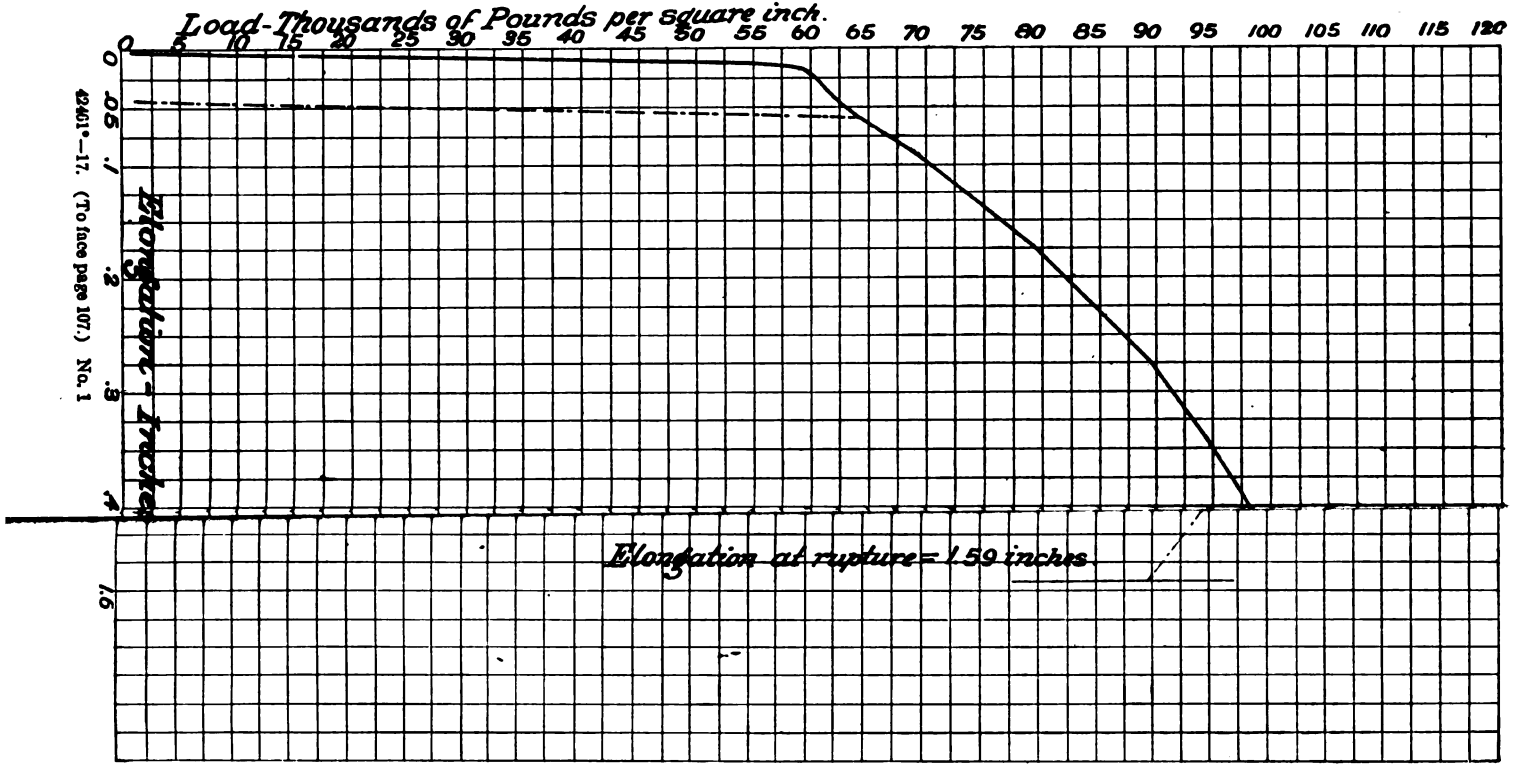
Load-Thousands of Pounds per square inch.
0 5 10 15 20 25 30 35 40 45 50 55 60 65 70 75 80 85 90 95 100 105 110 115 120
Elongation-Inches
0 .05 .1 .2 .3 .4 1.6
Elongation at rupture = 1.59 inches.

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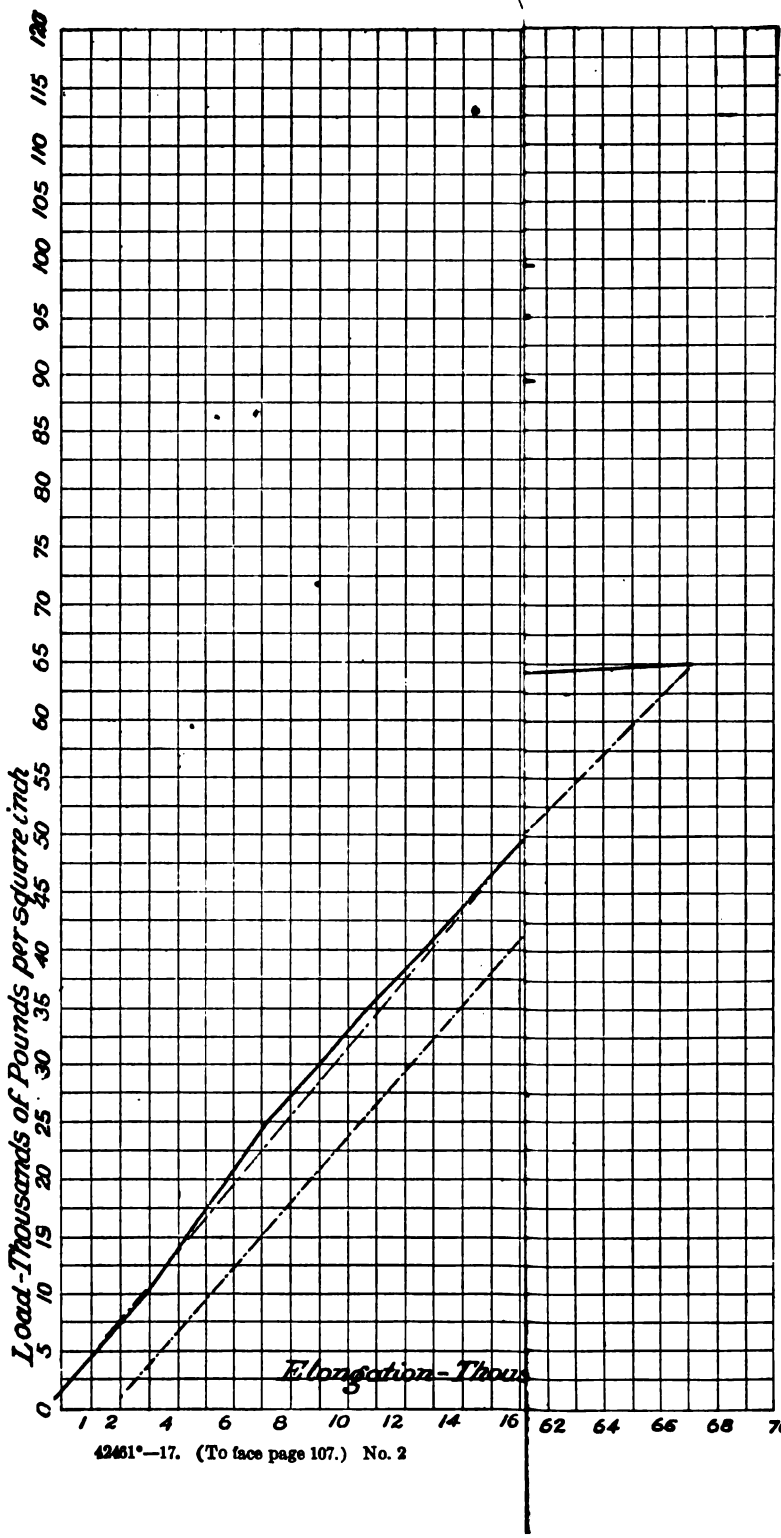


42461°—17. (To face page 107.) No. 2

TENSION TEST, SPECIMEN NO. 2.

Original condition.
Diameter, 1.009 inches.
Sectional area, 0.80 square inch.
Gauged length, 10 inches.

Applied loads.		In gauged length.		Applied loads.		In gauged length.	
Total pounds.	Pounds per square inch.	Elongation (inch).	Set (inch).	Total pounds.	Pounds per square inch.	Elongation (inch).	Set (inch).
800	1,000	0	0		59,000	0.0209 .0214	.....
	5,000	.0014	0		60,000	.0230	+0.0023
	10,000	.0032	.....		61,000	.0315	.....
	15,000	.0046	.....		62,000	.0420	.....
	20,000	.0061	.....		63,000	.0525	.....
	25,000	.0075	.....		64,000	.0595	.....
	30,000	.0093	.....		65,000	.670	.0415
	35,000	.0110	.....		70,000	.10	.....
	40,000	.0130	−.0003		75,000	.14	.....
	45,000	.0148	.....		80,000	.18	.....
	50,000	.0166	−.0002		85,000	.23	.....
	51,000	.0171	.....		90,000	.28	.....
	52,000	.0175	.....		95,000	.35	.....
	53,000	.0179	.....		100,000	.43	.....
	54,000	.0183	.....		105,000	.56	.....
	55,000	.0186	.....		110,000	.85	.....
	56,000	.0191	.....				
	57,000	.0196	.....	89,200	[2] 111,500	.....	.....
	[1] 58,000	.0202	.....				

[1] Yield point. [2] Tensile strength.

Elongation after fracture, 1.59 inches = 15.9 per cent.
Elongation of inch sections, .10, .19, .47*, .15, .13, .14, .12, .11, .10, .08.
Diameter at fracture, 0.73 inch.
Sectional area at fracture, 0.418 square inch.
Contraction of area, 47.7 per cent.
Position of fracture, 2.75 inches from the neck.
Appearance of fracture: Silky, cup shaped.

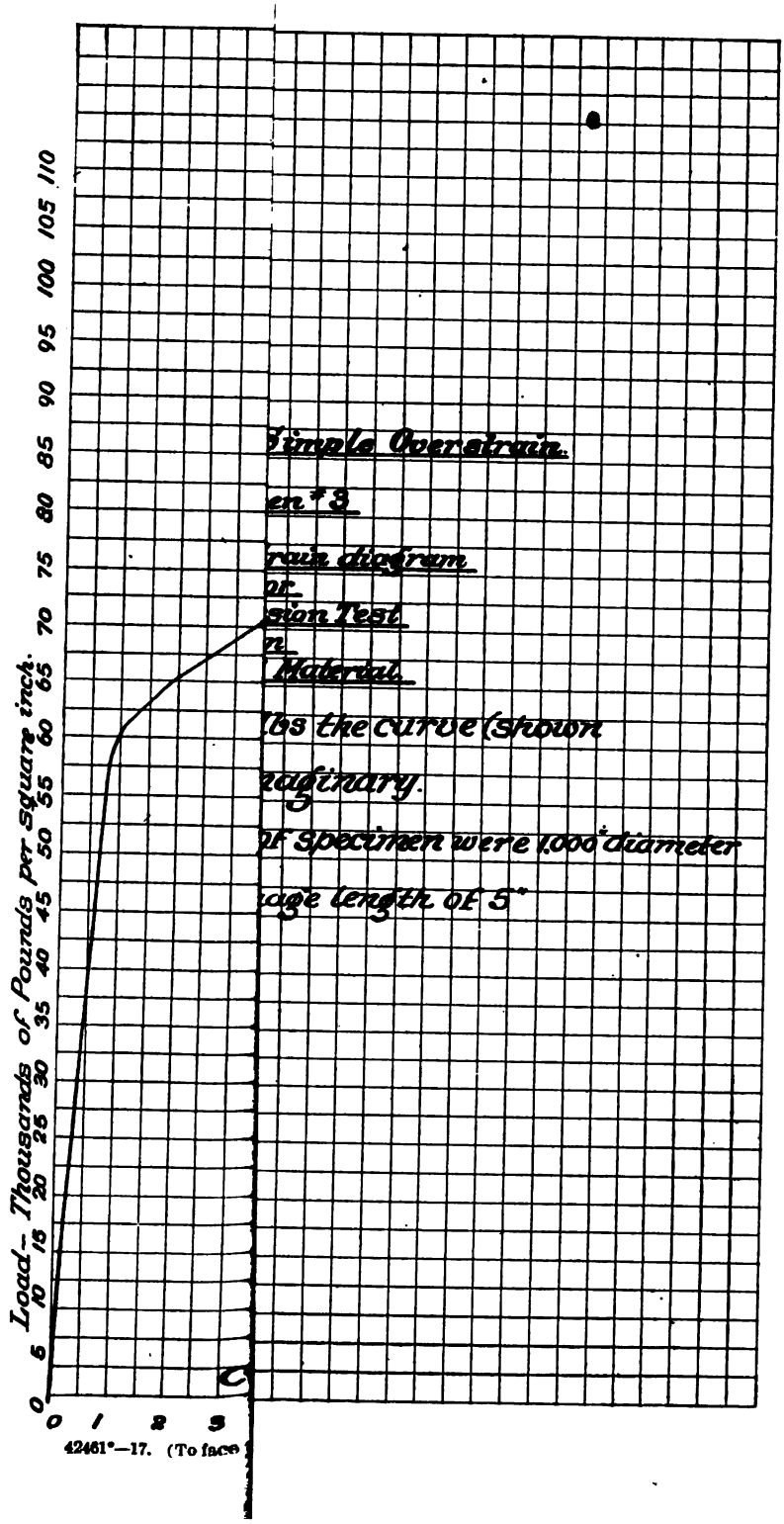
COMPRESSION TEST, SPECIMEN NO. 3.

Original condition.
Length of specimen, 6 inches.
Diameter of specimen, 1 inch.
Sectional area, 0.785 square inch.

Applied loads.		In gauged length.		Applied loads.		In gauged length.	
Total pounds.	Pounds per square inch.	Compression (inch).	Set (inch).	Total pounds.	Pounds per square inch.	Compression(inch).	Set (inch).
785	1,000	0	0	55,735	71,000	0.0388	.....
3,925	5,000	.0004	0	56,520	72,000	.0417	.....
7,850	10,000	.0012	.....	57,305	73,000	.0453	.....
11,775	15,000	.0020	.....	58,090	74,000	.0485	.....
15,700	20,000	.0029	.....	58,875	75,000	.0513	0.0373
19,625	25,000	.0038	.....	59,660	76,000	.0553	.....
23,550	30,000	.0047	.....	60,445	77,000	.0586	.....
27,475	35,000	.0056	.....	61,230	78,000	.0607	.....
31,400	40,000	.0065	.0001	62,015	79,000	.0638	.....
35,325	45,000	.0075	.....	62,800	80,000	.0678	.0525
39,250	50,000	.0082	.0003	63,585	81,000	.0709	.....
40,035	51,000	.0084	.....	64,370	82,000	.0738	.....
40,820	52,000	.0085	.....	65,155	83,000	.0771	.....
41,605	53,000	.0087	.....	65,940	84,000	.0808	.....
42,390	54,000	.0089	.....	66,725	85,000	.0843	.....
43,175	55,000	.0091	.....	67,510	86,000	.0881	.....
43,960	56,000	.0093	.....	68,295	87,000	.0923	.....
44,745	57,000	.0096	.....	69,080	88,000	.0958	.....
45,530	58,000	.0100	.....	69,865	89,000	.0991	.....
46,315	59,000	.0106	.....	70,650	90,000	.1028	.0850
47,100	60,000	.0112	.0016	71,435	91,000	.1063	.....
47,885	61,000	.0124 .0129	.....	72,220 73,005	92,000 93,000	.1085 .1115	.....
48,670	62,000	.0142	.....	73,790	94,000	.1143	.....
49,455	63,000	.0166	.....	74,575	95,000	.1183	.....
50,240	64,000	.0187	.....	75,360	96,000	.1217	.....
51,025	65,000	.0206	.0090	76,145	97,000	.1248	.....
51,810	66,000	.0236	.....	76,930	98,000	.1273	.....
52,595	67,000	.0261	.....	77,715	99,000	.1308	.....
53,380	68,000	.0293	.....	78,500	100,000	.1333	.1137
54,165	69,000	.0321	.....	85,400	[1] 108,790	.....	.....
54,950	70,000	.0354	.0225				

[1] Ultimate strength.

Failed by triple flexure.



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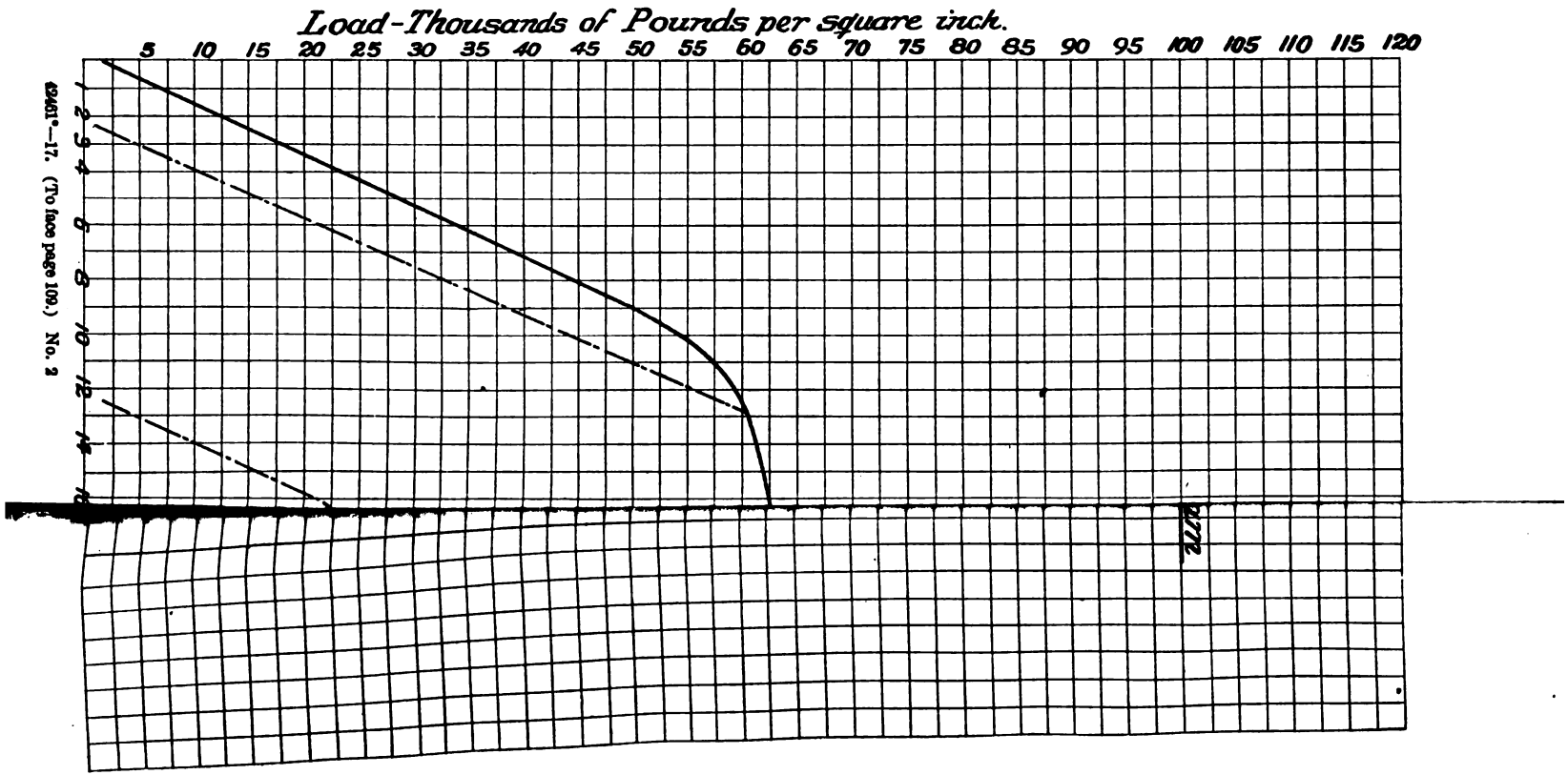
f Simple Overstrain
ecimen #3.
Stress-strain diagram
for
mpression Test
on
Original Material.
Load-Thousands of Pounds per square inch.
0 5 10 15 20 25 30 35 40 45 50 55 60 65 70 75 80 85 90 95 100 105 110
1 2 3 4 5 6
mpression-Thousands of an inch.

42461°—17. (To face

42461°—17. (To face page 109.) No. 1



42461°—17. (To face page 109.) No. 2

COMPRESSION TEST, SPECIMEN NO. 4.

Original material.
Length of specimen over all, 6 inches.
Diameter of specimen, 1 inch.
Sectional area, 0.785 square inch.
Gauged length, 5 inches.

Applied loads.		In gauged length.		Applied loads.		In gauged length.	
Total pounds.	Pounds per square inch.	Compression (inch).	Set (inch).	Total pounds.	Pounds per square inch.	Compression (inch).	Set (inch).
785	1,000	0	0	47,100	60,000	.0130	.0025
3,925	5,000	.0007	0	47,885	61,000	.0146	
7,850	10,000	.0017				.0152	
11,775	15,000	.0026		48,670	62,000	.0165	
15,700	20,000	.0035		49,455	63,000	.0187	
19,625	25,000	.0045		50,240	64,000	.0213	
23,550	30,000	.0054		51,025	65,000	.0242	.0125
27,475	35,000	.0063		51,810	66,000	.0275	
31,400	40,000	.0072	0	52,595	67,000	.0300	
35,325	45,000	.0082		53,380	68,000	.0330	
39,250	50,000	.0092	0	54,165	69,000	.0365	
40,035	51,000	.0095		54,950	70,000	.0390	.0256
40,820	52,000	.0097		58,875	75,000	.0535	
41,605	53,000	.0100		62,800	80,000	.0700	.0542
42,390	54,000	.0102		66,725	85,000	.0870	
43,175	55,000	.0105		70,650	90,000	.1050	.0877
43,960	56,000	.0108		74,575	95,000	.1220	
44,745	57,000	.0112		78,500	100,000	.1395	.1193
45,530	58,000	.0117		85,800	[1] 109,300		
46,315	59,000	.0122					

[1] Ultimate strength.

Failed by triple flexure.

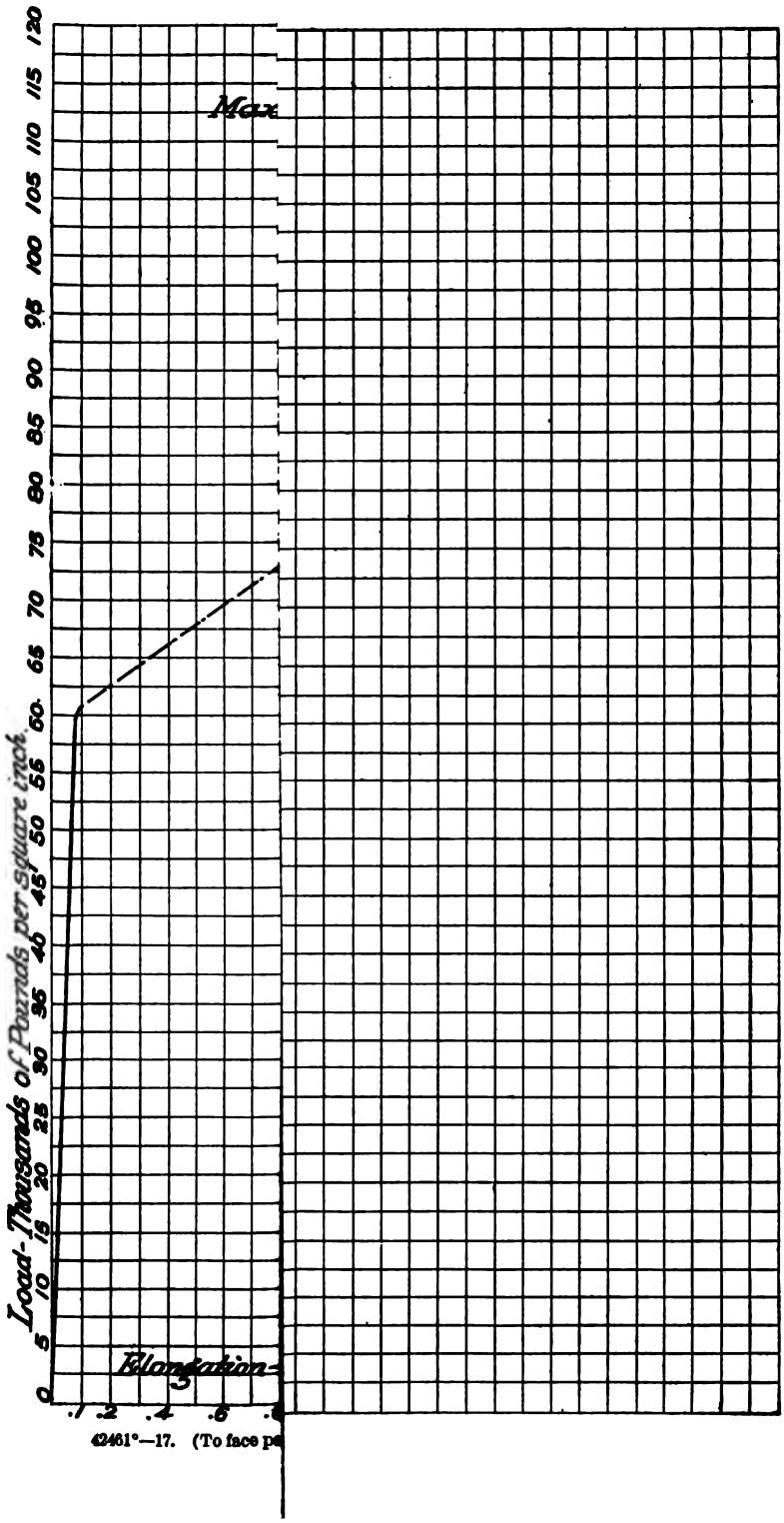
TENSION TEST, SPECIMEN NO. 5.

Original material.
Diameter, 1.009 inches.
Sectional area, 0.80 square inch.
Gauged length; 45 inches.
Length of specimen over all, 56 inches.
Nine 5-inch sections laid off on specimen.

Applied loads.		In gauged length.		Applied loads.		In gauged length.	
Total pounds.	Pounds per square inch.	Elongation (per cent).	Set (inch).	Total pounds.	Pounds per square inch.	Elongation (per cent).	Set (inch).
800	1,000	0	0		53,000	.0862	.....
	5,000	.0057	.0002		54,000	.0877	.....
	10,000	.0140	.....		55,000	.0896	.....
	15,000	.0224	.....		56,000	.0913	.....
	20,000	.0304	.....		57,000	.0932	.....
	25,000	.0385	.....		58,000	.0957	.....
	30,000	.0464	.....		[1] 59,000	.0987	.....
	35,000	.0547	.....		60,000	.1022	.0076
	40,000	.0627	.0004			.1036	
	45,000	.0731	.....		61,000	.1140	.....
	50,000	.0808	.0024		62,000	.1760	.0752
	51,000	.0825	.....	88,800	[2] 111,000	.....	.....
	52,000	.0842	.....				

[1] Yield point. [2] Tensile strength.

Elongation after fracture, 4.91 inches = 10.9 per cent.
Elongation of 5-inch section, .98, .62, .48, .53, .49, .44, .48, .44, .45
Diameter at fracture, 0.73 inch.
Sectional area, 0.418 square inch.
Contraction of area, 47.7 per cent.
Position of fracture, 7.50 inches from the neck.
Appearance of fracture: Silky.



length.

et (inch).

.0076

.0752

l, .45.

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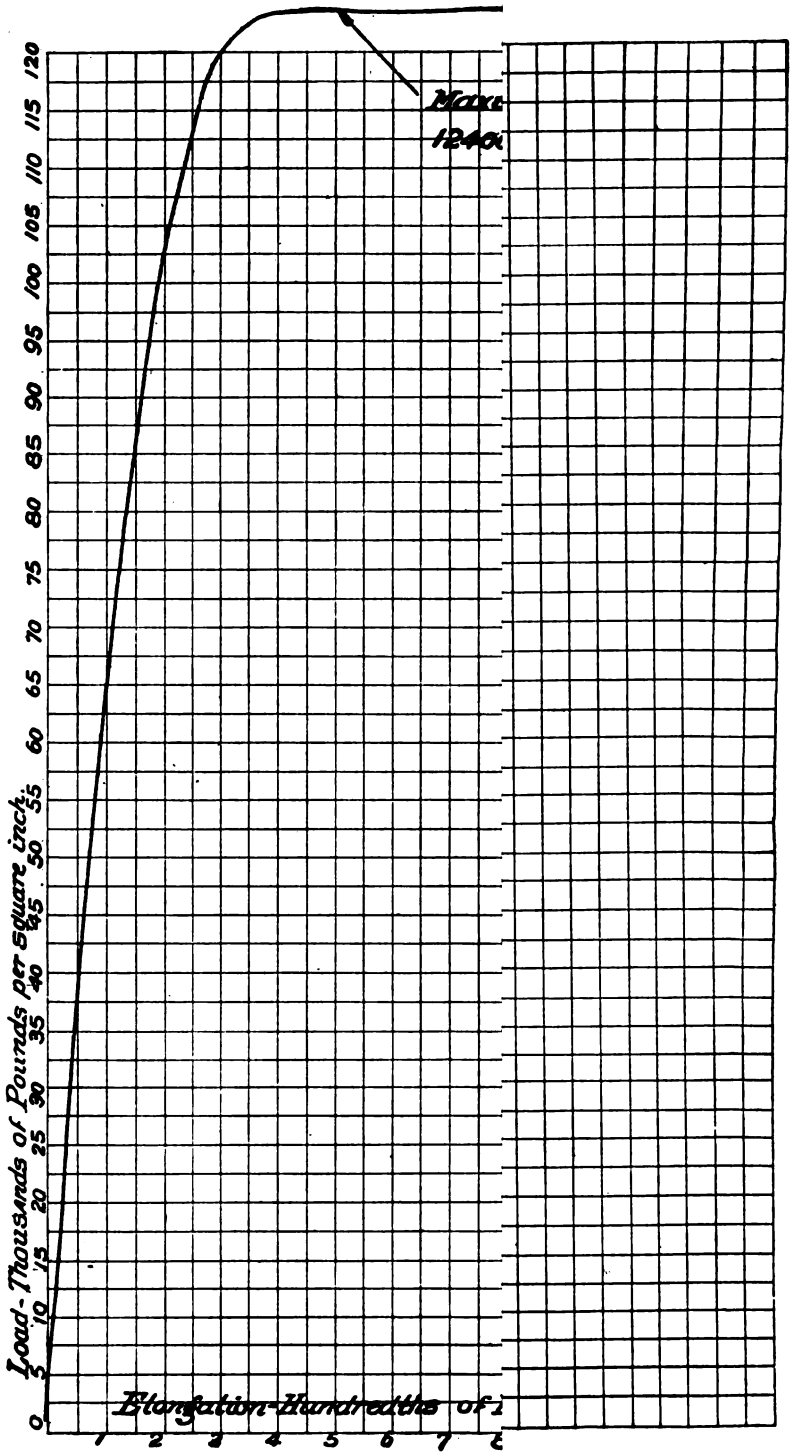
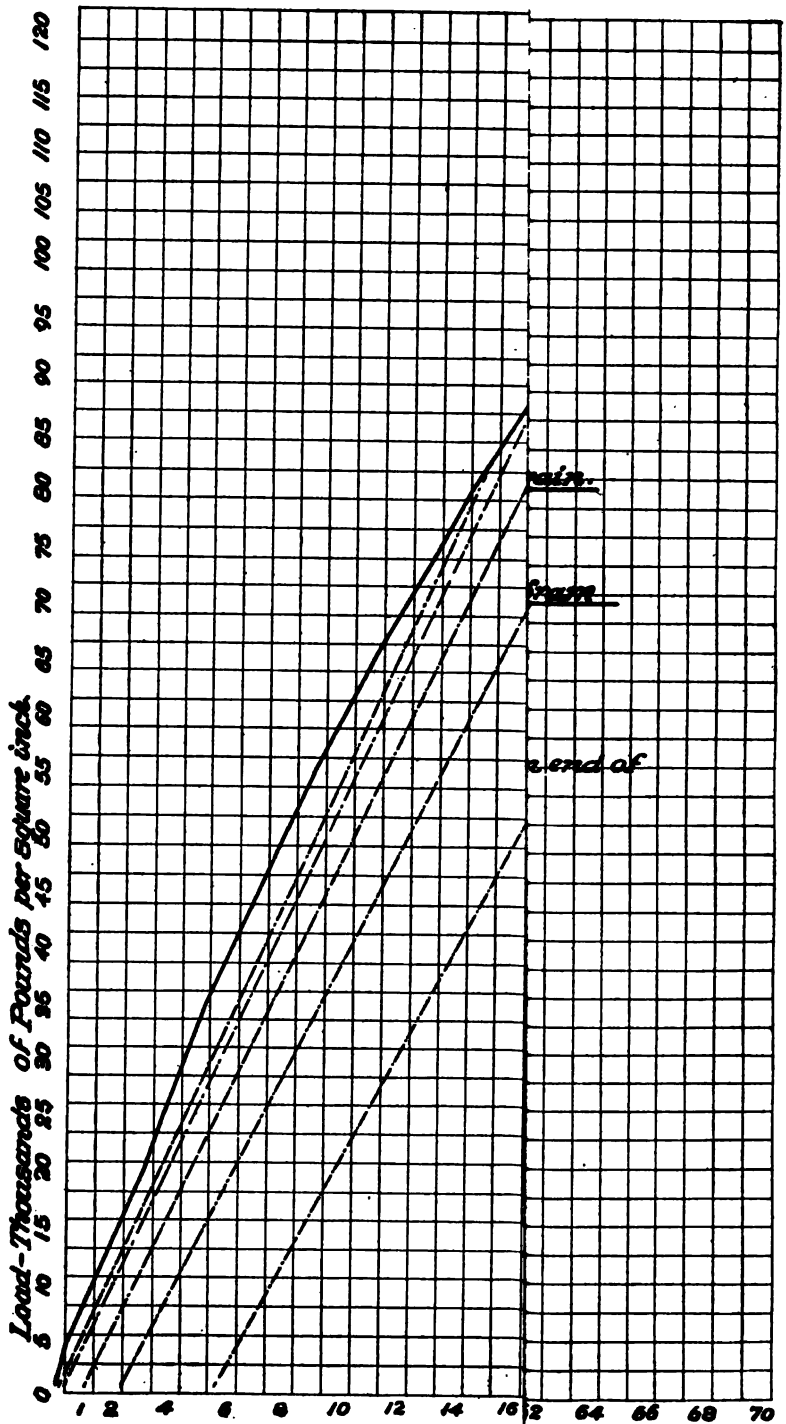
Load-Thousands of Pounds per square inch.
0
5
10
15
20
25
30
35
40
45
50
55
60
65
70
75
80
85
90
95
100
105
110
115
120
0
1
2
3
Per cent inch.
ple Overstrain
m. # 6.
-Strain diagram
ted
aterial.
a gauge length of 45 inches
1-9 were machined from
this specimens.



42461°—17. (To face page 111.) No. 1



42461°—17. (To face page 111.) No. 2

TENSION TEST, SPECIMEN NO. 6.

Overstrained material. Rested one week.
Diameter, 0.564 inch.
Sectional area, 0.25 square inch.
Gauged length, 5 inches.

Applied loads.		In gauged length.		Applied loads.		In gauged length.	
Total pounds.	Pounds per square inch.	Elongation (inch).	Set (inch).	Total pounds.	Pounds per square inch.	Elongation (inch).	Set (inch).
250	1,000	0	0		104,000	.0222	.....
	5,000	.0004	0		105,000	.0227	.....
	10,000	.0013	.....		106,000	.0233	.....
	15,000	.0022	.....		107,000	.0237	.....
	20,000	.0031	.....		108,000	.0242	.....
	25,000	.0036	.....		109,000	.0246	.....
	30,000	.0046	.....		110,000	.0250	.0023
	35,000	.0054	.....		111,000	.0257	.....
	40,000	.0063	0		112,000	.0262	.....
	45,000	.0073	.....		113,000	.0266	.....
	50,000	.0082	0		114,000	.0272	.....
	55,000	.0092	.....		115,000	.0277	.....
	60,000	.0103	.....		116,000	.0284	.....
	65,000	.0113	.....		117,000	.0289	.....
	70,000	.0125	.....		118,000	.0297	.....
	75,000	.0137	.....		119,000	.0304	.....
	80,000	.0148	.....		120,000	.0318	.....
	81,000	.0150	.....		121,000	.0336	.....
	82,000	.0154	.0001		122,000	.0356	.....
	83,000	.0156	.....		123,000	.0385	.0174
	84,000	.0158	.....			.0454	
	85,000	.0161	.....		[1] 124,000	.05	.....
	86,000	.0164	.....		123,000	.06	.....
	87,000	.0166	.....			.12	
	88,000	.0168	.....		119,600	.13	.....
	89,000	.0171	.....		118,800	.15	.....
	90,000	.0174	.0003		117,600	.16	.....
	91,000	.0177	.....		116,800	.17	.....
	92,000	.0180	.....		115,600	.18	.....
	93,000	.0182	.....		114,400	.19	.....
	94,000	.0185	.....		113,200	.20	.....
	95,000	.0188	.....		112,000	.21	.....
	96,000	.0191	.....		110,000	.22	.....
	97,000	.0194	.....		108,000	.23	.....
	98,000	.0198	.....		107,600	.24	.....
	99,000	.0201	.....		106,000	.25	.....
	100,000	.0205	.0010		104,000	.26	.....
	101,000	.0208	.....		102,000	.27	.....
	102,000	.0214	.....	25,300	[2] 101,200	.....	.....
	103,000	.0218	.....				

[1] Maximum load. [2] Breaking load.

Elongation after fracture, 0.25 inch = 5 per cent.
Elongation of inch sections, 0.24,[1] 0.01, 0, 0, 0.
Diameter at fracture, 0.434 inch. Sectional area, 0.1479 square inch. Contraction, 40.8 per cent.
Position of fracture, 0.85 inch from the neck.
Appearance of fracture: Fine granular with silky center.

[1] Micrometer removed and readings taken with vernier.

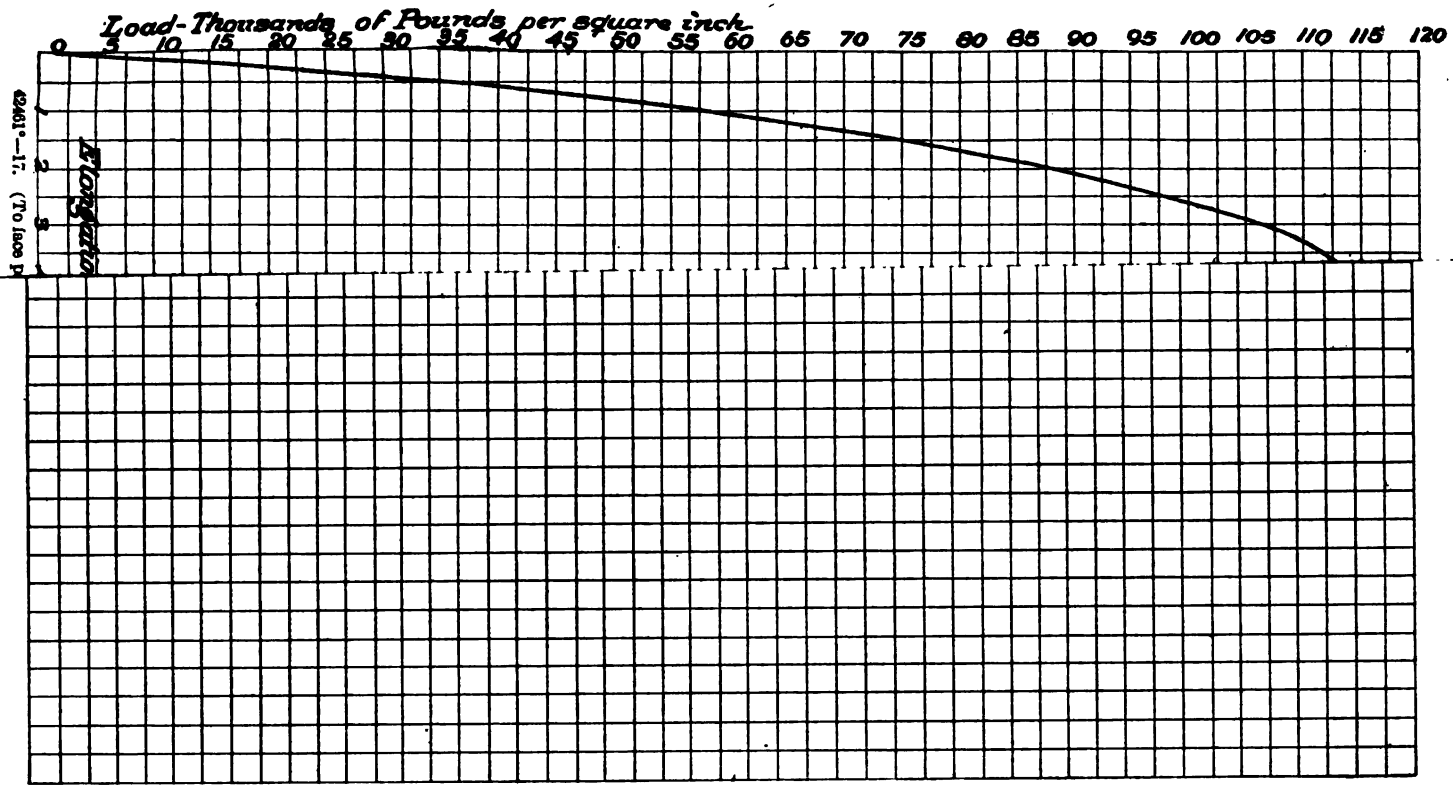
TENSION TEST, SPECIMEN NO. 7.

Overstrained material. Rested one week.
Diameter, 0.564 inch.
Sectional area, 0.25 square inch.
Gauged length, 5 inches.

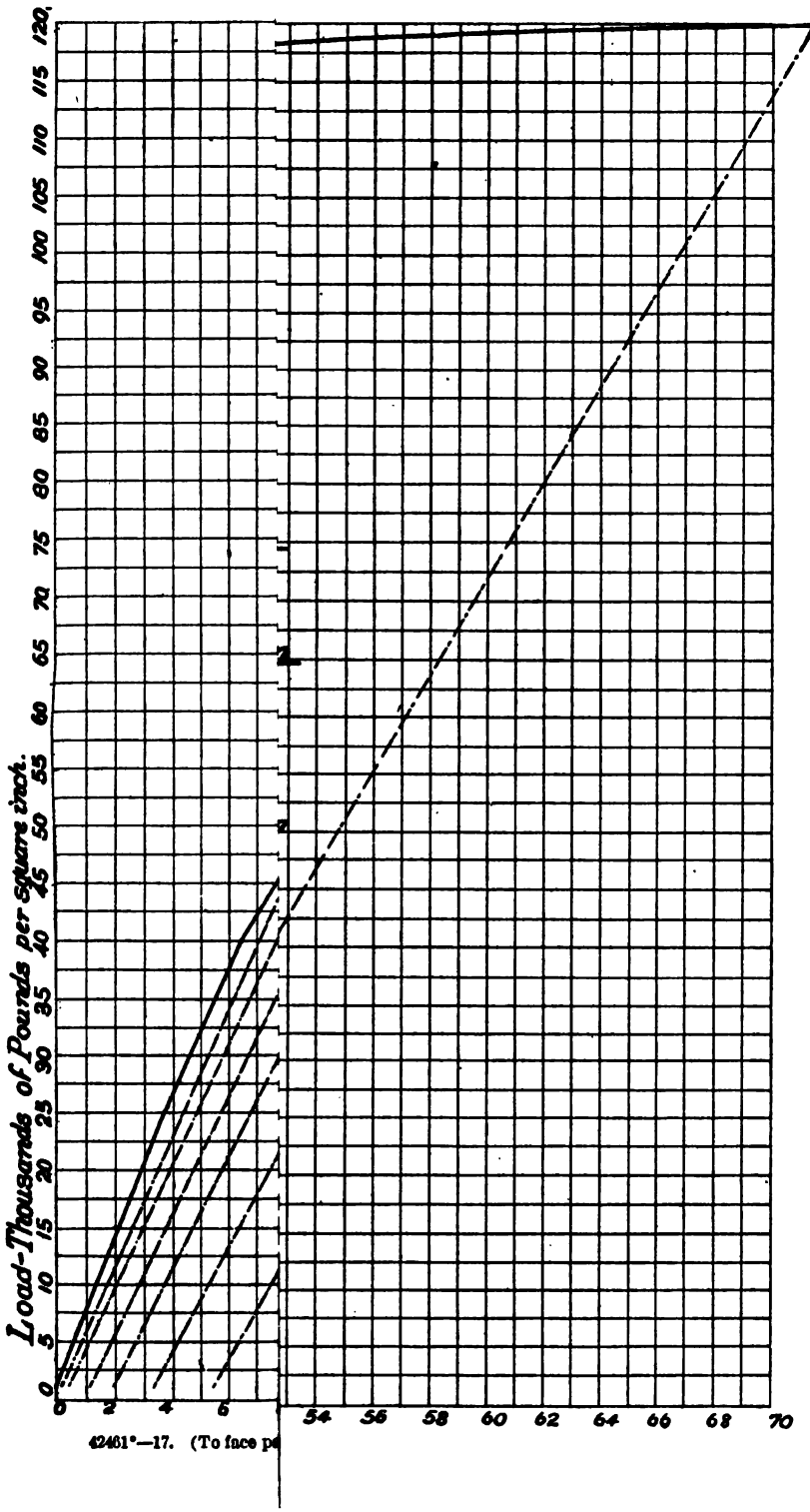
Applied loads.		In gauged length.		Applied loads.		In gauged length.	
Total pounds.	Pounds per square inch.	Elongation (inch).	Set (inch).	Total pounds.	Pounds per square inch.	Elongation (inch).	Set (inch).
250	1,000	0	0	250	85,000	.0199	.....
	5,000	.0006	0		86,000	.0204	.....
	10,000	.0015	.....		87,000	.0208	.....
	15,000	.0022	.....		88,000	.0215	.....
	20,000	.0030	.....		89,000	.0220	.....
	25,000	.0038	.....		90,000	.0225	.0034
	30,000	.0047	.....		91,000	.0232	.....
	35,000	.0056	.....		92,000	.0241	.....
	40,000	.0065	0		93,000	.0243	.....
	45,000	.0077	.....		94,000	.0246	.....
	50,000	.0090	.0002		95,000	.0250	.....
	51,000	.0093	.....		96,000	.0256	.....
	52,000	.0095	.....		97,000	.0260	.....
	53,000	.0097	.....		98,000	.0267	.....
	54,000	.0100	.....		99,000	.0270	.....
	55,000	.0102	.....		100,000	.0276	.0055
	56,000	.0105	.....		101,000	.0284	.....
	57,000	.0108	.....		102,000	.0289	.....
	58,000	.0111	.....		103,000	.0299	.....
	59,000	.0113	.....		104,000	.0299	.....
	60,000	.0116	.0004		105,000	.0305	.....
	61,000	.0121	.....		106,000	.0314	.....
	62,000	.0123	.....		107,000	.0321	.....
	63,000	.0125	.....		108,000	.0330	.....
	64,000	.0128	.....		109,000	.0339	.....
	65,000	.0131	.....		110,000	.0350	.0103
	66,000	.0134	.....		111,000	.0369	.....
	67,000	.0137	.....		112,000	.0380	.....
	68,000	.0140	.....		113,000	.0389	.....
	69,000	.0142	.....		114,000	.0404	.....
	70,000	.0145	.0012		115,000	.0427	.....
	71,000	.0149	.....		116,000	.0445	.....
	72,000	.0152	.....		117,000	.0472	.....
	73,000	.0155	.....		118,000	.0528	.....
	74,000	.0158	.....		119,000	.0587	.....
	75,000	.0162	.....		120,000	.0710	[1] .0430
	76,000	.0165	.....		[2] 121,000	.16	.....
	77,000	.0168	.....		114,000	.17	.....
	78,000	.0172	.....		112,800	.18	.....
	79,000	.0175	.....		110,400	.19	.....
	80,000	.0180	.0020		108,400	.20	.....
	81,000	.0184	.....		106,000	.21	.....
	82,000	.0188	.....		104,400	.22	.....
	83,000	.0191	.....		100,800	.23	.....
	84,000	.0195	.....	24,800	[3] 99,200	.....	.....

[1] Micrometer removed and readings taken with a vernier. [2] Maximum load. [3] Breaking load.

Elongation after fracture, 0.25 inch.
Elongation of inch sections, .03, .01, .01, .01, .18.
Diameter at fracture, 0.43 inch. Sectional area, 0.145 square inch. Contraction, 41.9 per cent. Position of fracture, 0.70 inch from the neck. Appearance of fracture, fine granular with silky center.

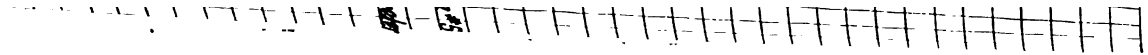


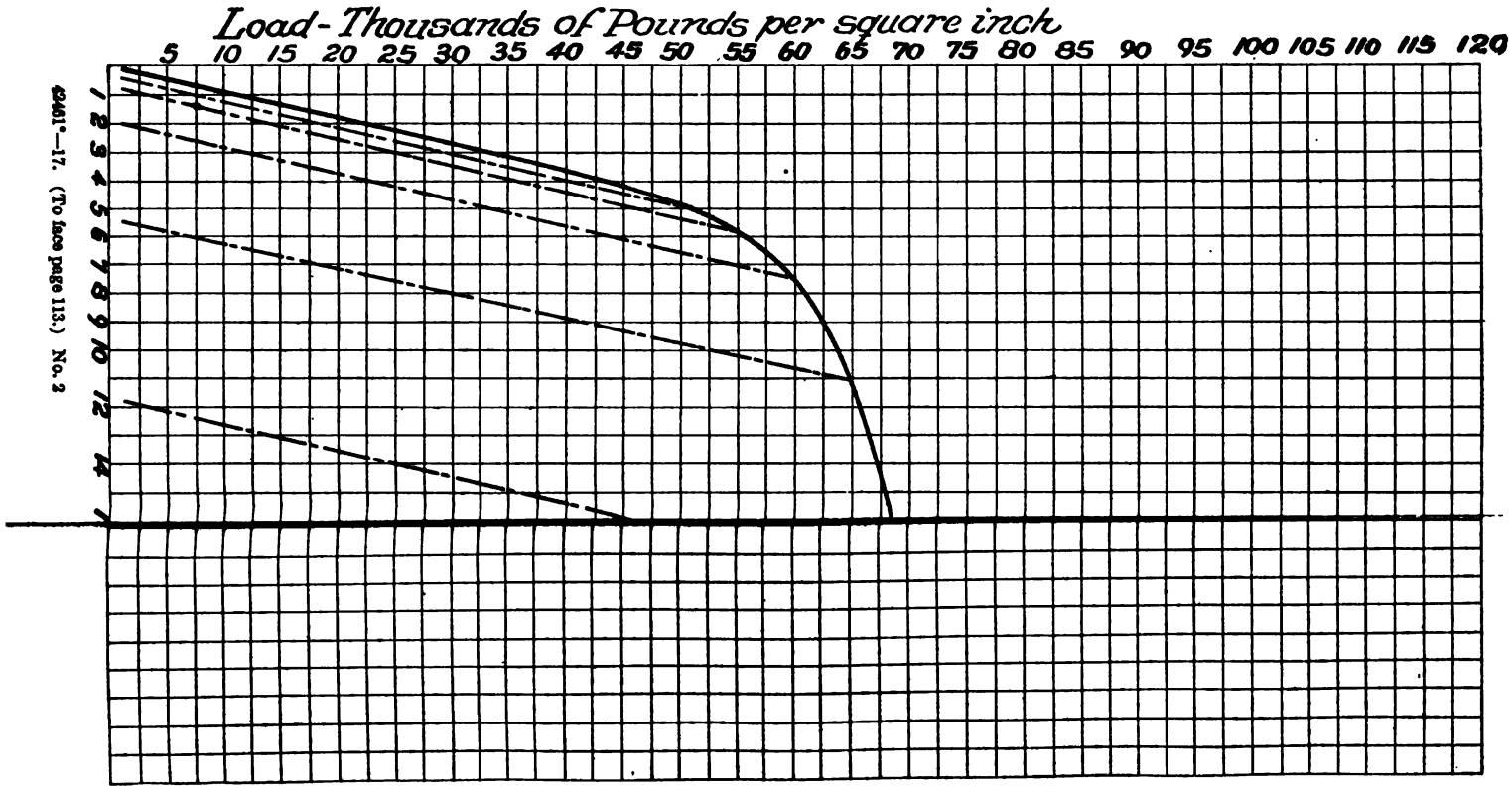
42461°—17. (To face p



42461°—17. (To face pa

42461°—17. (To face page 113.) No. 1





2961°—17. (To face page 113.) No. 2

COMPRESSION TEST, SPECIMEN NO. 8.

Overstrained material. Rested seven weeks.
Diameter of specimen, 0.874 inch.
Sectional area, 0.6 square inch.
Gauged length, 3 inches.
Length of specimen over all, 4⅜ inches.

Applied loads.		In gauged length.		Applied loads.		In gauged length.	
Total pounds.	Pounds per square inch.	Compression (inch).	Set (inch).	Total pounds.	Pounds per square inch.	Compression (inch).	Set (inch).
600	1,000	0	0	29,400	49,000	.0048	.....
3,000	5,000	.0006	0	30,000	50,000	.0050	.0004
6,000	10,000	.0009	.....	30,600	51,000	.0051	.....
9,000	15,000	.0014	.....	31,200	52,000	.0053	.....
12,000	20,000	.0018	.0001	31,800	53,000	.0054	.....
15,000	25,000	.0023	.....	32,400	54,000	.0057	.....
15,600	26,000	.0024	.....	33,000	55,000	.0059	.0008
16,200	27,000	.0024	.....	33,600	56,000	.0062	.....
16,800	28,000	.0025	.....	34,200	57,000	.0065	.....
17,400	29,000	.0026	.....	34,800	58,000	.0068	.....
18,000	30,000	.0027	.....	35,400	59,000	.0072	.....
18,600	31,000	.....	.....	36,000	60,000	.0076	.0020
19,200	32,000	.....	.....	36,600	61,000	.0082	.....
19,800	33,000	.....	.....	37,200	62,000	.0088	.....
20,400	34,000	.....	.....	37,800	63,000	.0094	.....
21,000	35,000	.0033	.....	38,400	64,000	.0102	.....
21,600	36,000	.0033	.....	39,000	65,000	.0112	.0055
22,200	37,000	.0034	.....	39,600	66,000	.0135	.....
22,800	38,000	.0035	.....	40,200	67,000	.0144	.....
23,400	39,000	.0036	.....	40,800	68,000	.0156	.....
24,000	40,000	.0038	.0001	41,400	69,000	.0168	.....
24,600	41,000	.0039	.....	42,000	70,000	.0183	.0118
25,200	42,000	.0040	.....	45,000	75,000	.0268	.....
25,800	43,000	.0041	.....	48,000	80,000	.0358	.....
26,400	44,000	.0042	.....	51,000	85,000	.0453	.....
27,000	45,000	.0043	.....	54,000	90,000	.0558	.0478
27,600	46,000	.0044	.....	57,000	95,000	.0703	.....
28,200	47,000	.0046	.....	60,000	100,000	.0838	.0758
28,800	48,000	.0047	.....	66,700	[1] 111,166	.....	.....

[1] Ultimate strength.

Failed by triple flexure.

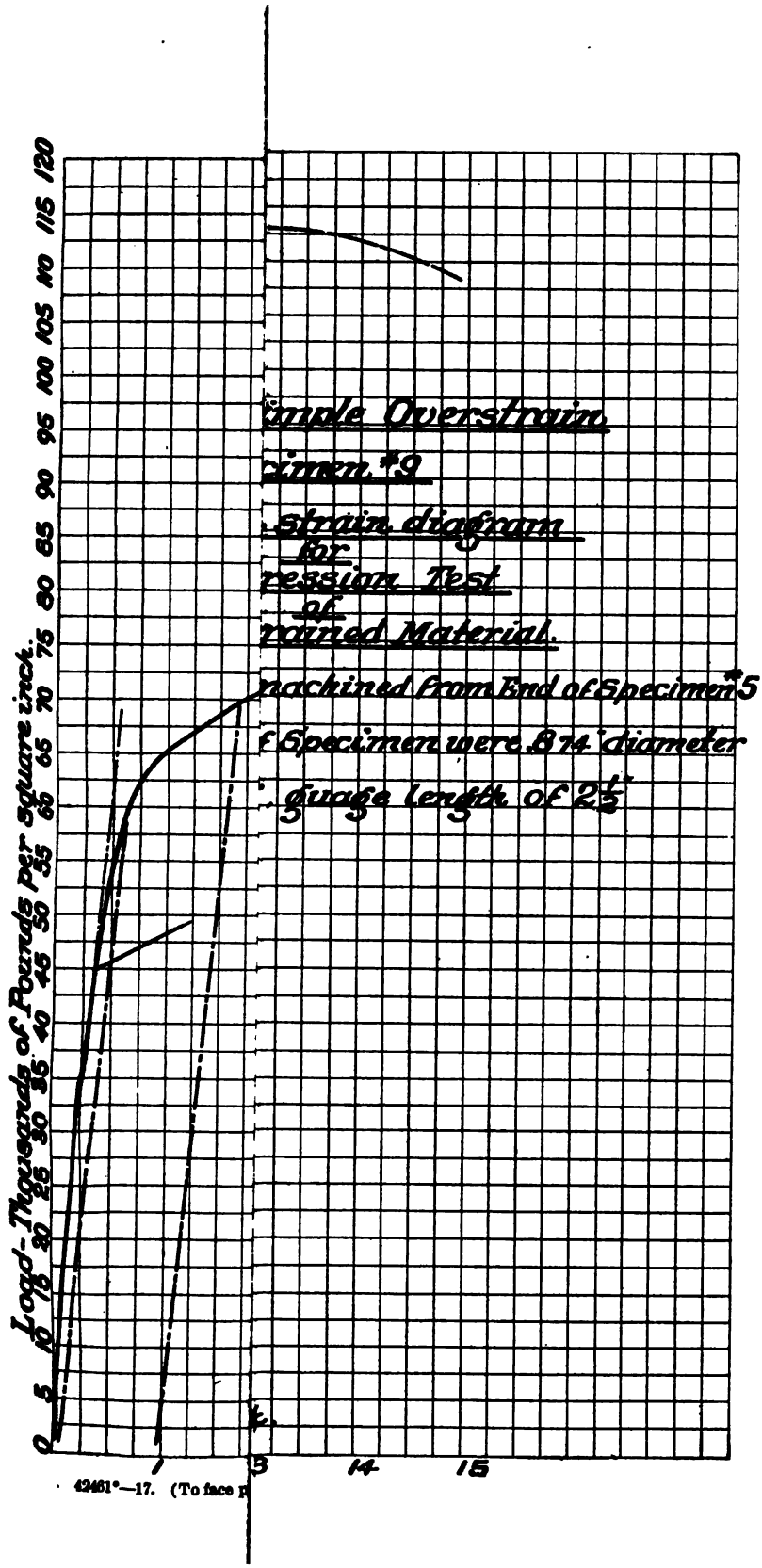
COMPRESSION TEST, SPECIMEN NO. 9.

Overstrained material. Rested seven weeks.
Diameter of specimen, 0.874 inch.
Sectional area, 0.600 square inch.
Gauge length, 2½ inches.
Length of specimen over all, 4⅜ inches.

Applied loads.		In gauged length.		Applied loads.		In gauged length.	
Total pounds.	Pounds per square inch.	Compression (inch).	Set (inch).	Total pounds.	Pounds per square inch.	Compression (inch).	Set (inch).
600	1,000	0	0	29,400	49,000	0.0044	.....
3,000	5,000	0	0	30,000	50,000	.0046	0
6,000	10,000	.0003	.....	30,600	51,000	.0048	.....
9,000	15,000	.0007	.....	31,200	52,000	.0049	.....
12,000	20,000	.0012	0	31,800	53,000	.0051	.....
15,000	25,000	.0017	.....	32,400	54,000	.0052	.....
15,600	26,000	.0018	.....	33,000	55,000	.0054	.0001
16,200	27,000	.0019	.....	33,600	56,000	.0056	.....
16,800	28,000	.0020	.....	34,200	57,000	.0059	.....
17,400	29,000	.0021	.....	34,800	58,000	.0061	.....
18,000	30,000	.0022	0	35,400	59,000	.0064	.....
18,600	31,000	.0023	.....	36,000	60,000	.0067	.0004
19,200	32,000	.0024	.....	36,600	61,000	.0073	.....
19,800	33,000	.0025	.....	37,200	62,000	.0078	.....
20,400	34,000	.0026	.....	37,800	63,000	.0082	.....
21,000	35,000	.0027	.....	38,400	64,000	.0089	.....
21,600	36,000	.0028	.....	39,000	65,000	.0099	.0029
22,200	37,000	.0029	.....	39,600	66,000	.0117	.....
22,800	38,000	.0031	.....	40,200	67,000	.0129	.....
23,400	39,000	.0032	.....	40,800	68,000	.0141	.....
24,000	40,000	.0033	0	41,400	69,000	.0155	.....
24,600	41,000	.0034	.....	42,000	70,000	.0172	.0097
25,200	42,000	.0035	.....	45,000	75,000	.0272	.....
25,800	43,000	.0036	.....	48,000	80,000	.0374	.....
26,400	44,000	.0038	.....	51,000	85,000	.0484	.....
27,000	45,000	.0039	.....	54,000	90,000	.0611	.0517
27,600	46,000	.0040	.....	57,000	95,000	.0734	.....
28,200	47,000	.0042	.....	60,000	100.000	.0817	.0712
28,800	48,000	.0043	.....	67,900	[1] 113,166	.....	.....

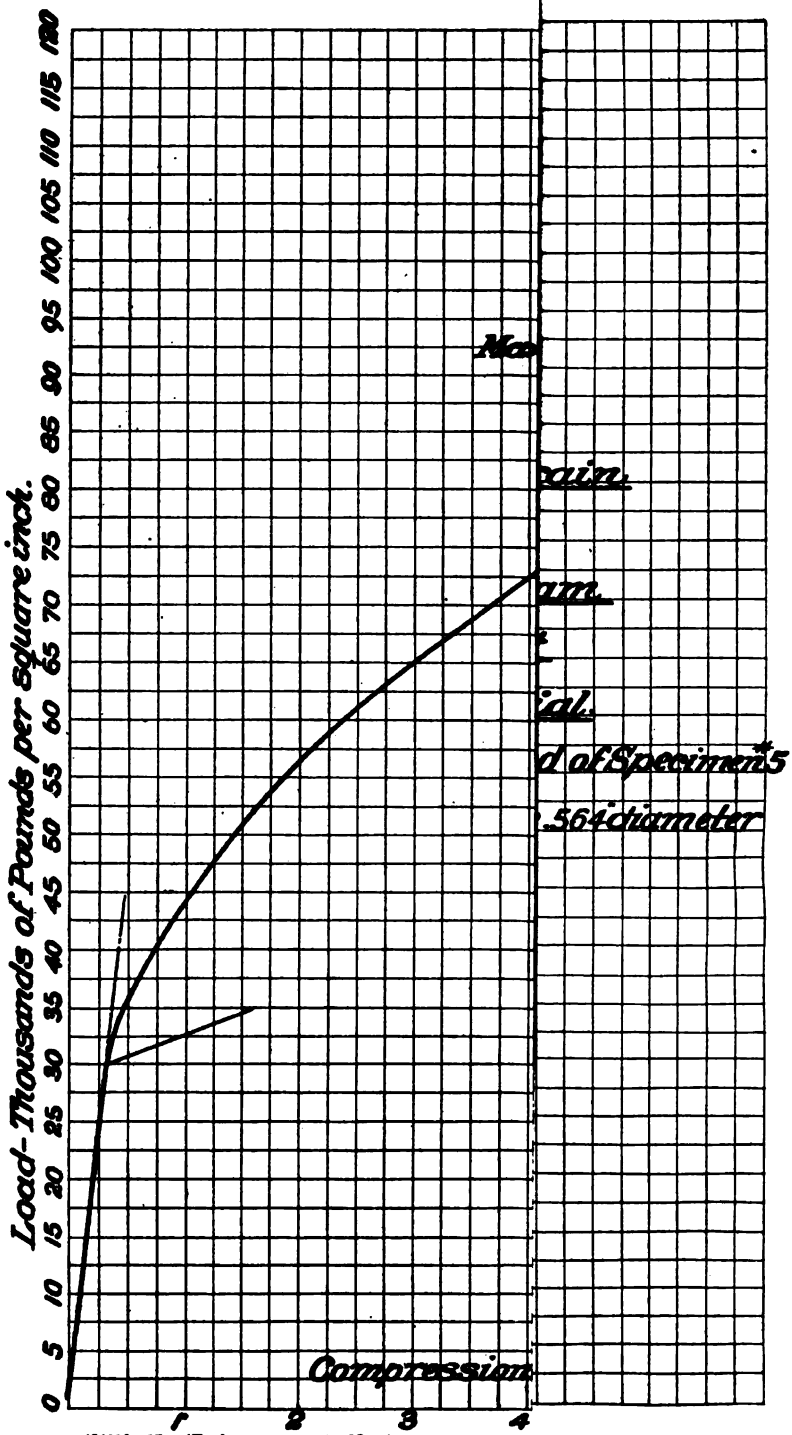
[1] Ultimate strength.

Failed by triple flexure.


Load-Thousands of Pounds per square inch.
0 5 10 15 20 25 30 35 40 45 50 55 60 65 70 75 80 85 90 95 100 105 110 115 120
imple Overstrain
zimen. #9
Strain diagram
for
ression Test
of
rained Material.
nachined from End of Specimen #5
f Specimen were .874 diameter
guage length of 2½
3
14
15

Load - Thousands of Pounds per Square inch
0 5 10 15 20 25 30 35 40 45 50 55 60 65 70 75 80 85 90 95 100 105 110 115 120
1 2 3 4 6 7
of Simple Overstrain.
Specimen #9
Stress-strain diagram
for
Compression Test
of
Overstrained Material

43M1'-17. (To face page


Load-Thousands of Pounds per square inch.
0 5 10 15 20 25 30 35 40 45 50 55 60 65 70 75 80 85 90 95 100 105 110 115 120
Compression
1 2 3 4
Ma
ain.
am.
ial.
d of Specimen 5
.564 diameter

42461°—17. (To face page 115.) No. 1

42461°—17. (To face page 115.) No. 2

COMPRESSION TEST, SPECIMEN NO. 10.

Overstrained material. Rested seven weeks.
Diameter of specimen, 0.564 inch.
Sectional area, 0.25 square inch.
Gauge length, 3 inches.
Length of specimen over all, 4 inches.

Applied loads.		In gauged length.		Applied loads.		In gauged length.	
Total pounds.	Pounds per square inch.	Compression (inch).	Set (inch).	Total pounds.	Pounds per square inch.	Compression (inch).	Set (inch).
250	1,000	0	0	11,000	44,000	0.0103	.....
1,250	5,000	.0006	.0001	11,250	45,000	.0109	.....
2,500	10,000	.0011	.....	11,500	46,000	.0116	.....
3,750	15,000	.0017	.....	11,750	47,000	.0122	.....
5,000	20,000	.0022	.....	12,000	48,000	.0130	.....
6,250	25,000	.0028	.....	12,250	49,000	.0138	.....
7,500	30,000	.0036	.....	12,500	50,000	.0146	.0093
8,750	35,000	.0051	.0018	13,750	55,000	.0187	.....
9,000	36,000	.0057	.....	15,000	60,000	.0241	.....
9,250	37,000	.0062	.....	16,250	65,000	.0301	.....
9,500	38,000	.0066	.....	17,500	70,000	.0371	.0296
9,750	39,000	.0071	.....	18,750	75,000	.0436	.....
10,000	40,000	.0076	.0038	20,000	80,000	.0511	.....
10,250	41,000	.0086	.....	21,250	85,000	.0571	.0481
10,500	42,000	.0091	.....	22,600	[1] 90,400	.....	.....
10,750	43,000	.0096	.....				

[1] Ultimate strength.

Failed by triple flexure.

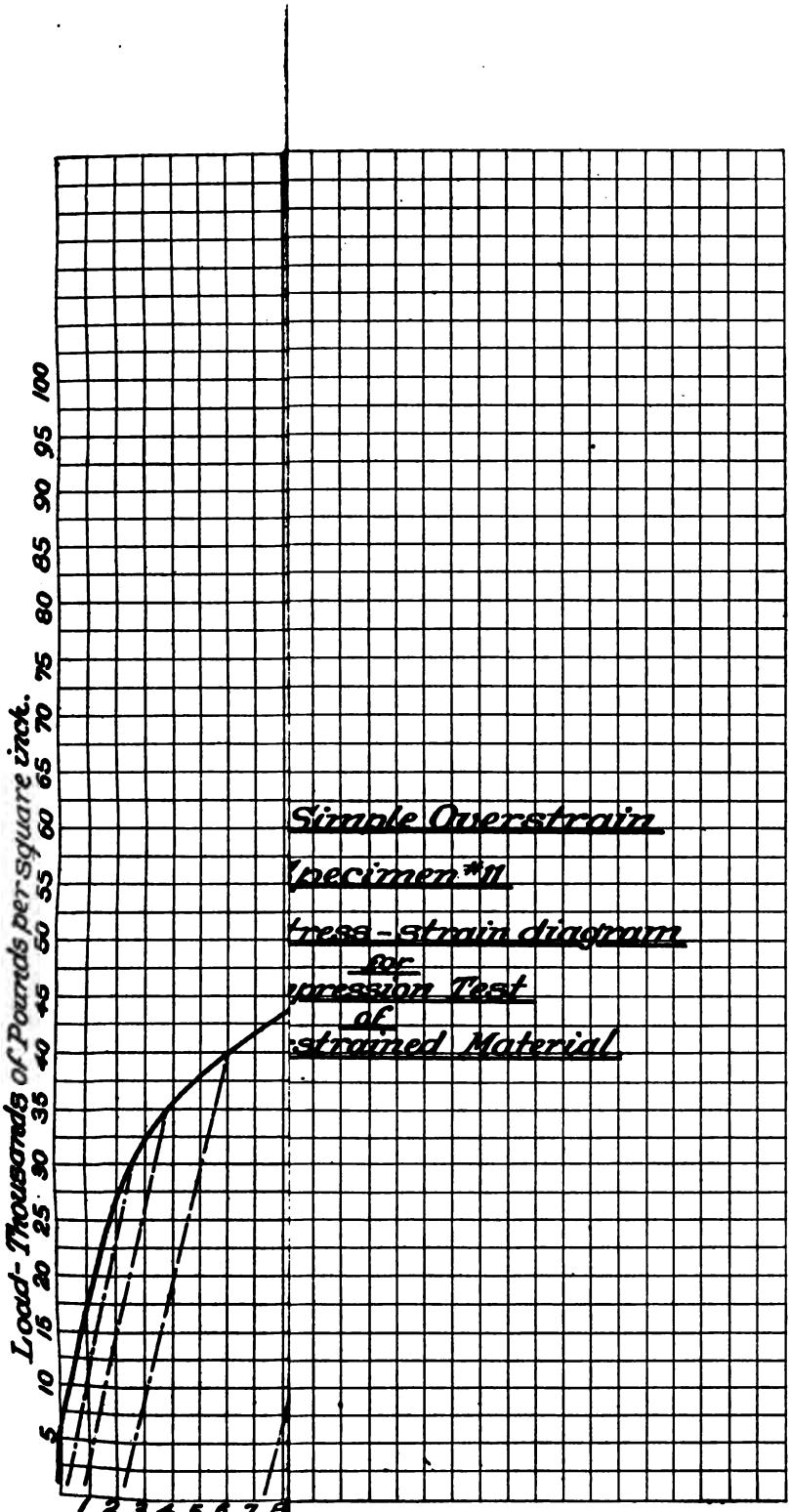
COMPRESSION TEST, SPECIMEN NO. 11.

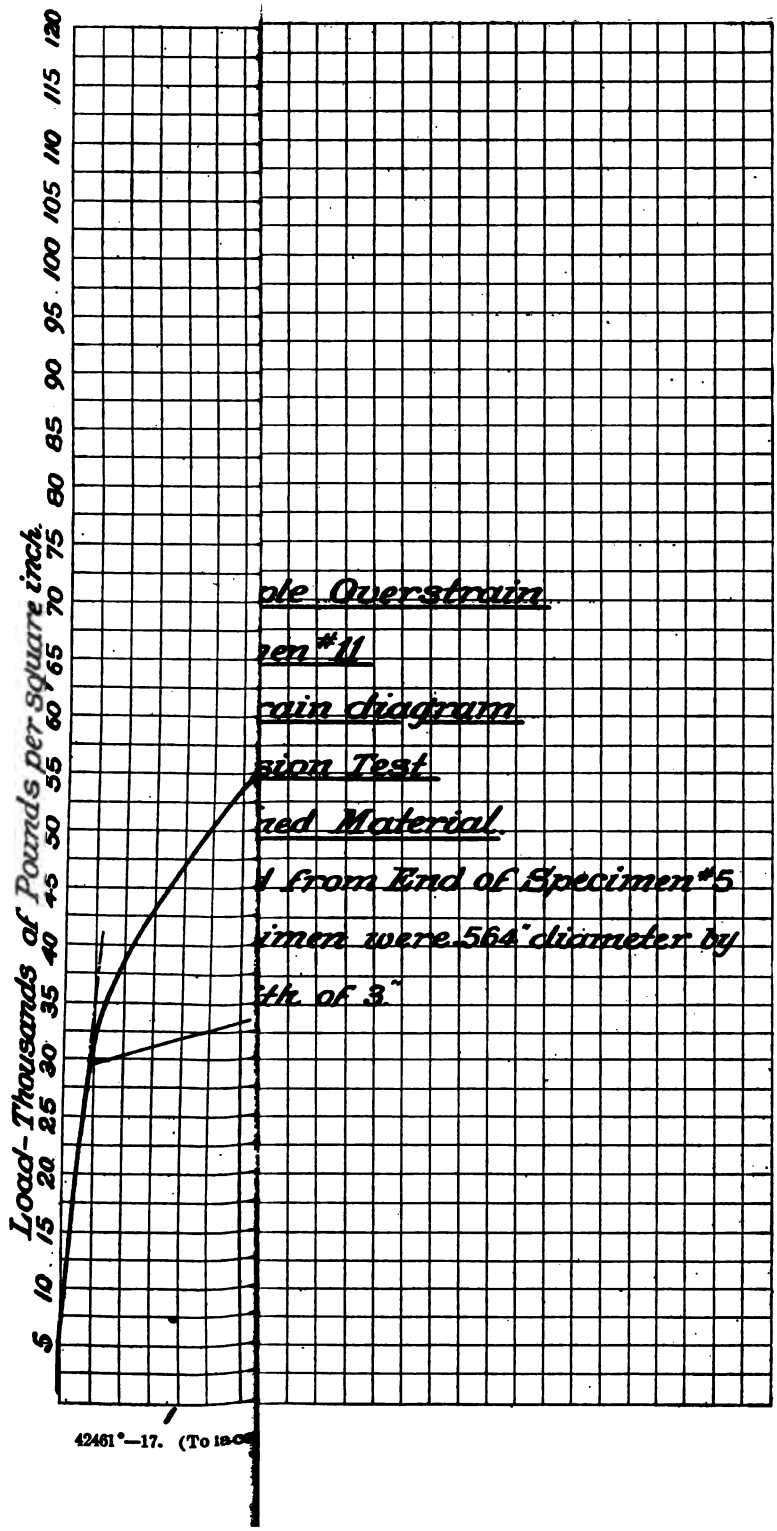
Overstrained material. Rested seven weeks.
Diameter of specimen, 0.564 inch.
Sectional area, 0.25 square inch.
Gauge length, 3 inches.
Length of specimen over all, 4 inches.

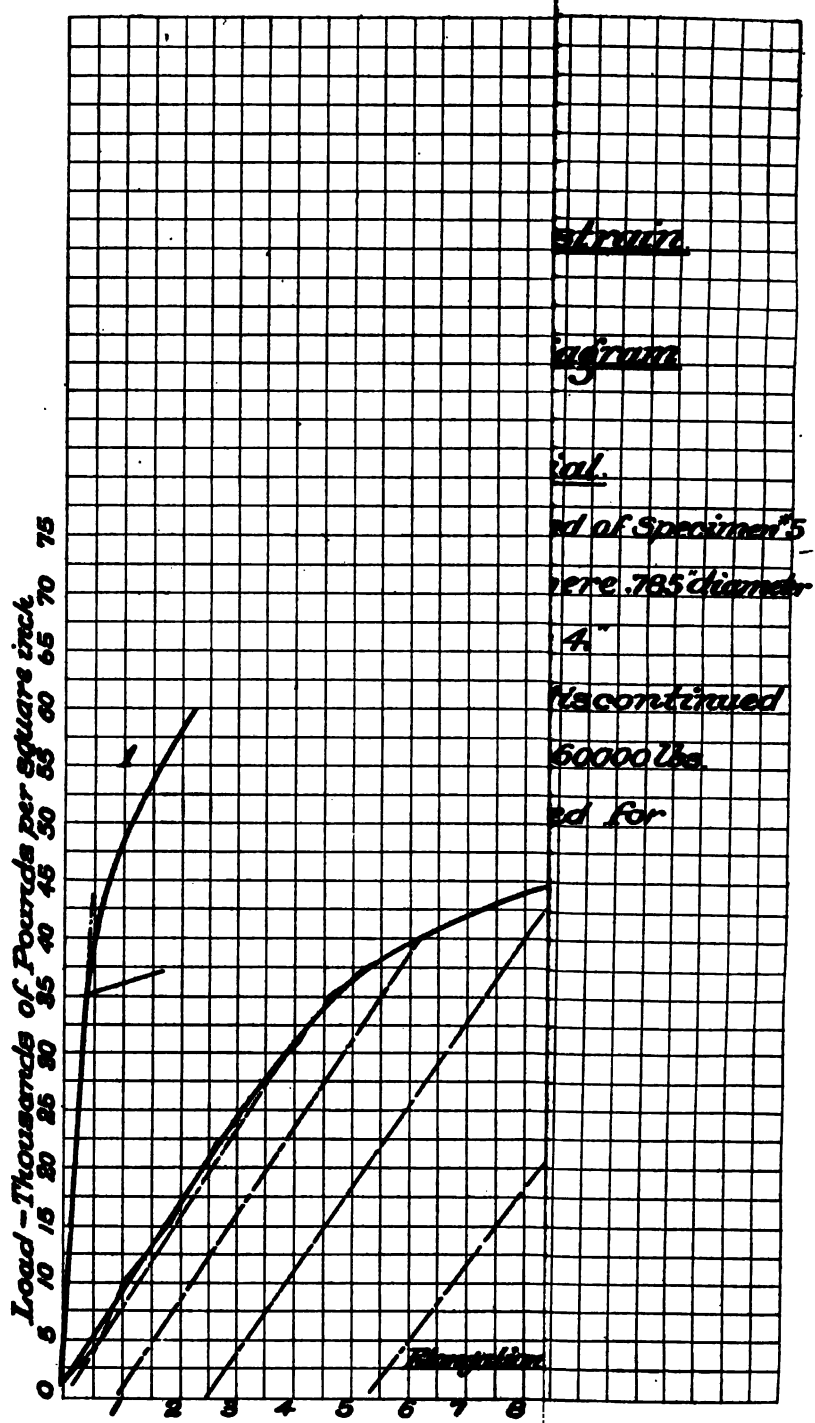
Applied loads.		In gauged length.		Applied loads.		In gauged length.	
Total pounds.	Pounds per square inch.	Compression (inch).	Set (inch).	Total pounds.	Pounds per square inch.	Compression (inch).	Set (inch).
250	1,000	0	0	11,000	44,000	.0085	.....
1,250	5,000	0	0	11,250	45,000	.0091	.....
2,500	10,000	.0004	.....	11,500	46,000	.0098	.....
3,750	15,000	.0009	.....	11,750	47,000	.0104	.....
5,000	20,000	.0014	0	12,000	48,000	.0112	.....
5,250	21,000	.0015	.....	12,250	49,000	.0119	.....
5,500	22,000	.0016	.....	12,500	50,000	.0126	.0075
5,750	23,000	.0017	.....	12,750	51,000	.0135	.....
6,000	24,000	.0019	.....	13,000	52,000	.0141	.....
6,250	25,000	.0020	.....	13,250	53,000	.0148	.....
6,500	26,000	.0021	.....	13,500	54,000	.0154	.....
6,750	27,000	.0022	.....	13,750	55,000	.0161	.....
7,000	28,000	.0024	.....	14,000	56,000	.0171	.....
7,250	29,000	.0025	.....	14,250	57,000	.0179	.....
7,500	30,000	.0027	.0003	14,500	58,000	.0187	.....
7,750	31,000	.0029	.....	14,750	59,000	.0196	.....
8,000	32,000	.0031	.....	15,000	60,000	.0207	.0144
8,250	33,000	.0033	.....	15,250	61,000	.0225	.....
8,500	34,000	.0036	.....	15,500	62,000	.0232	.....
8,750	35,000	.0039	.0009	15,750	63,000	.0240	.....
9,000	36,000	.0044	.....	16,000	64,000	.0253	.....
9,250	37,000	.0048	.....	16,250	65,000	.0264	.....
9,500	38,000	.0052	.....	17,500	70,000	.0323	.....
9,750	39,000	.0056	.....	18,750	75,000	.0384	.....
10,000	40,000	.0060	.0024	20,000	80,000	.0427	.....
10,250	41,000	.0068	.....	21,250	85,000	.0424?	.....
10,500	42,000	.0074	.....	22,800	[1] 91,200	.....	.....
10,750	43,000	.0079	.....				

[1] Ultimate strength.

Failed by triple flexure.


Load - Thousands of Pounds per Square inch.
5 10 15 20 25 30 35 40 45 50 55 60 65 70 75 80 85 90 95 100
1 2 3 4 5 6 7 8
Simple Overstrain
Specimen #11
Stress - strain diagram
for
Compression Test
of
Strained Material


Load-Thousands of Pounds per Square inch.
5 10 15 20 25 30 35 40 45 50 55 60 65 70 75 80 85 90 95 100 105 110 115 120
ole Overstrain
en #11
rain diagram
sion Test
ned Material
d from End of Specimen #5
imen were .564" diameter by
th of 3"



42461°—17. (To face page 117.)

SPECIMEN NO. 12.

Length of specimen over all, 5.25 inches.
Gauge length, 4 inches.
Diameter of specimen, 0.785 inch.
Sectional area, 0.484 square inch.

Applied loads.		In gauged length.		Applied loads.		In gauged length.	
Total pounds.	Pounds per square inch.	Compression (inch).	Set (inch).	Total pounds.	Pounds per square inch.	Compression (inch).	Set (inch).
484	1,000	0	0	17,424	36,000	.0050	.....
2,420	5,000	.0007	0	17,908	37,000	.0052	.....
4,840	10,000	.0011	.....	18,392	38,000	.0055	.....
7,260	15,000	.0019	.....	18,876	39,000	.0059	.....
9,680	20,000	.0025	0	19,360	40,000	.0063	.0011
10,164	21,000	.0026	.....	19,844	41,000	.0067	.....
10,648	22,000	.0027	.....	20,328	42,000	.0071	.....
11,132	23,000	.0029	.....	20,812	43,000	.0076	.....
11,616	24,000	.0031	.....	21,296	44,000	.0081	.....
12,100	25,000	.0032	.....	21,780	45,000	.0088	.0027
12,584	26,000	.0033	.....	22,264	46,000	.0099	.....
13,068	27,000	.0035	.....	22,748	47,000	.0108	.....
13,552	28,000	.0037	.....	23,232	48,000	.0115	.....
14,036	29,000	.0038	.....	23,716	49,000	.0121	.....
14,520	30,000	.0040	.0002	24,200	50,000	.0129	.0055
15,004	31,000	.0042	.....	25,168	52,000	.0154	.....
15,488	32,000	.0043	.....	26,136	54,000	.0169	.....
15,972	33,000	.0044	.....	27,104	56,000	.0190	.....
16,456	34,000	.0046	.....	28,072	58,000	.0214	.....
16,940	35,000	.0047	.....	29,040	[1] 60,000	.0235	.0147

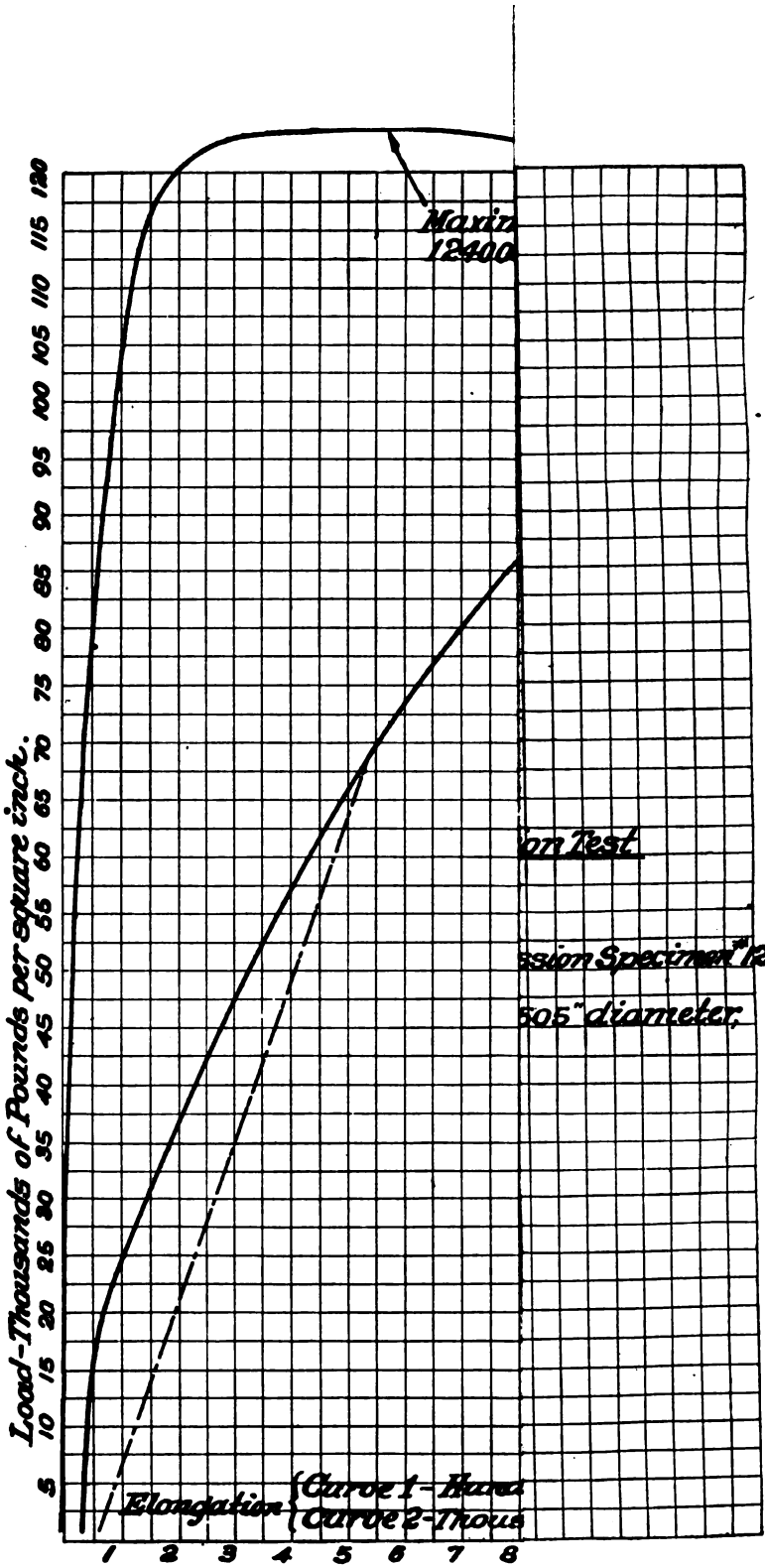
[1] Test discontinued. Specimen to be turned into a tension specimen.

SPECIMEN NO. 12 T.

Diameter of specimen, 0.505 inch.
Sectional area, 0.20 square inch.
Gauged length, 2 inches.

Applied loads.		In gauged length.		Applied loads.		In gauged length.	
Total (pounds).	Pounds per square inch.	Elongation (inch).	Set (inch).	Total (pounds).	Pounds per square inch.	Elongation (inch).	Set (inch).
200	1,000	0.0004	0.0008	18,800	94,000	0.0095	.....
1,000	5,000	.0005	.0005	19,000	95,000	.0096	.....
2,000	10,000	.0005	.....	19,200	96,000	.0099	.....
3,000	15,000	.0006	.....	19,400	97,000	.0103	.....
4,000	20,000	.0008	.....	19,600	98,000	.0105	.....
4,200	21,000	.00085	.....	19,800	99,000	.0108	.....
4,400	22,000	.0009	.....	20,000	100,000	.0111	0.0025
4,600	23,000	.00095	.....	20,200	101,000	.0114	.....
4,800	24,000	.0010	.....	20,400	102,000	.0116	.....
5,000	25,000	.00105	.....	20,600	103,000	.0118	.....
5,200	26,000	.00115	.....	20,800	104,000	.0120	.....
5,400	27,000	.0012	.....	21,000	105,000	.0122	.....
5,600	28,000	.0013	.....	21,200	106,000	.0125	.....
5,800	29,000	.00135	.....	21,400	107,000	.0128	.....
6,000	30,000	.0014	.0003	21,600	108,000	.0132	.....
6,200	31,000	.0016	.....	21,800	109,000	.0136	.....
6,400	32,000	.0017	.....	22,000	110,000	.0140	.0043
6,600	33,000	.00185	.....	22,200	111,000	.0145	.....
6,800	34,000	.0019	.....	22,400	112,000	.0149	.....
7,000	35,000	.00195	.....	22,600	113,000	.0153	.....
7,200	36,000	.00205	.....	22,800	114,000	.0158	.....
7,400	37,000	.0021	.....	23,000	115,000	.0164	.....
7,600	38,000	.00215	.....	23,200	116,000	.0172	.....
7,800	39,000	.00225	.....			.0175	
8,000	40,000	.0023	.0003	23,400	117,000	.0180	.....
8,200	41,000	.0024	.....	23,600	118,000	.0190	.....
8,400	42,000	.0025	.....	23,800	119,000	.0199	.....
8,600	43,000	.0026	.....	24,000	120,000	.0214	.0098
8,800	44,000	.0027	.....	24,200	121,000	.0240	.....
9,000	45,000	.0028	.....	24,400	122,000	.0260	.....
9,200	46,000	.0029	.....	24,600	[1] 123,000	.0310	.....
9,400	47,000	.0030	.....	24,800	124,000	.06	.....
9,600	48,000	.0032	.....			.10	
9,800	49,000	.0033	.....	24,800	[2] 124,000	.....	.....
10,000	50,000	.0034	.0002	23,700	118,500	.10	.....
10,200	51,000	.0035	.....			.11	
10,400	52,000	.0036	.....	23,800	119,000	.11+	.....
10,600	53,000	.0036	.....			.115	
10,800	54,000	.0037	.....	23,700	118,500	.12	.....
11,000	55,000	.0038	.....	23,600	118,000	.12	.....
11,200	56,000	.0039	.....			.12+	
11,400	57,000	.0040	.....			.125	
11,600	58,000	.0041	.....	23,500	117,500	.13	.....
11,800	59,000	.0042	.....			.13+	
12,000	60,000	.0044	.0004	23,400	117,000	.13+	.....
12,200	61,000	.0045	.....			.135	
12,400	62,000	.0046	.....	23,300	116,500	.14	.....
12,600	63,000	.0048	.....	23,200	116,000	.14	.....
12,800	64,000	.0049	.....			.145	
13,000	65,000	.0050	.....			.15	
13,200	66,000	.0051	.....	23,100	115,500	.15+	.....
13,400	67,000	.0052	.....	23,000	115,000	.155	.....
13,600	68,000	.0053	.....	22,900	114,500	.16	.....
13,800	69,000	.0054	.....	22,800	114,000	.165	.....
14,000	70,000	.0056	.0007	22,700	113,500	.17	.....
14,200	71,000	.0057	.....	22,600	113,000	.17+	.....
14,400	72,000	.0059	.....	22,500	112,500	.175	.....
14,600	73,000	.0060	.....	22,400	112,000	.18	.....
14,800	74,000	.0062	.....	22,300	111,500	.18+	.....
15,000	75,000	.0063	.....	22,200	111,000	.185	.....
15,200	76,000	.0064	.....	22,100	110,500	.19	.....
15,400	77,000	.0065	.....	22,000	110,000	.19+	.....
15,600	78,000	.0066	.....	21,900	109,500	.195	.....
15,800	79,000	.0068	.....	21,800	109,000	.20	.....
16,000	80,000	.0071	.0011	21,700	108,500	.20+	.....
16,200	81,000	.0073	.....	21,600	108,000	.205	.....
16,400	82,000	.0075	.....	21,500	107,500	.21	.....
16,600	83,000	.0076	.....	21,400	107,000	.21	.....
16,800	84,000	.0077	.....	21,300	106,500	.215	.....
17,000	85,000	.0079	.....	21,200	106,000	.215	.....

[1] Instrument removed. Measurements taken with a vernier.
[2] Maximum load. Measurements taken on decreasing loads.


Load-Thousands of Pounds per square inch.
5 10 15 20 25 30 35 40 45 50 55 60 65 70 75 80 85 90 95 100 105 110 115 120
Maxim
12400
on Test.
sion Specimen #2
505" diameter.
Elongation {Curve 1 - Hand
Curve 2 - Thous
1 2 3 4 5 6 7 8

Applied loads.		In gauged length.		Applied loads.		In gauged length.	
Total (pounds).	Pounds per square inch.	Elongation (inch).	Set (inch).	Total (pounds).	Pounds per square inch.	Elongation (inch).	Set (inch).
17,200	86,000	0.0081	.....	21,100	105,500	0.22	.....
17,400	87,000	.0083	.....	21,000	105,000	.22	.....
17,600	88,000	.0085	.....	20,900	104,500	.225	.....
17,800	89,000	.0087	.....	20,800	104,000	.225	.....
18,000	90,000	.0088	0.0016	20,700	103,500	.23	.....
18,200	91,000	.0090	.....	20,600	103,000	.23	.....
18,400	92,000	.0092	.....	20,500	102,500	.23+	.....
18,600	93,000	.0093	.....	20,400	[1] 102,000	.235	.....

[1] Specimen fractured.

Elongation after fracture, 0.24 = 12 per cent.
Diameter at fracture, 0.39 inch.
Sectional area at fracture, 0.119 square inch.
Contraction of area, 40.3 per cent.
Position of fracture, 0.75 inch from the neck.
Appearance of fracture: Silky, trace of granulation.

THE EFFECTS OF SIMPLE TENSILE OVERSTRAIN ON THE TENSILE PROPERTIES OF STEEL, WITH SPECIAL REGARD TO THE ELASTIC LIMIT.

This test was carried out under the direction of Dr. Henry Fay at the Massachusetts Institute of Technology.

The purpose of this series of tests was to discover some of the physical effects of simple tensile overstrain, with more especial attention paid to the effect on the elastic limit in tension.

With this object in view, an effort was made to find what information there was already available along this line in order that this test should not cover any ground which had already been fully and satisfactorily covered by any previous work. It seemed difficult to discover any articles bearing directly on the subject of simple overstrain, most of the reported tests being of a more complicated nature. In a few cases, however, general statements as to the effects of simple overstrain were found but with no accompanying confirmatory data.

Howe,[1] in an article on simple overstrain, quotes from Bairstow,[2] who says that simple overstrain raises the yield point nearly to the overstraining stress, and, if followed by rest or gentle heating, raises the proportionality limit beyond that stress. He then goes on to say that if such overstrain is preceded by stress reversals, then, even if followed by competent heating, instead of raising the proportionality limit beyond the overstraining stress it may fail to raise it even to that stress.

Mason,[3] in an article on "The phenomenon of yield point of metals under stress," makes the statement that only after a long period of rest after the overstraining will it be found that the maximum strength has been raised.

Another author makes a statement to the effect that the elastic limit, yield point, and maximum strength are all raised by simple overstrain.

For the present no further reference will be made to any other works. However, it should be said that recently articles have been found which deal directly with the subject, extracts from which will appear in the discussion of the results of this test.

OUTLINE.

Two programs were adopted—the first, in which the amount of overstrain was to be varied, keeping the period of rest constant; and the second, in which the time of rest was to be varied while the amounts of overstrain remained the same.

As the result of the preliminary tests on specimens in the annealed condition, the following schedules were decided upon: First, in the case of the variable overstrain series, one week was adopted as the period of rest. Then for the various amounts of overstrain the stress-strain diagram of the annealed specimen was taken and four loads

[1] Proceedings of the American Society for Testing Materials, 1914, Part II, page 7.
[2] Collected Researches, National Phys. Lab., Vol. VII, page 187.
[3] Trans. Liverpool Eng. Soc., Vol. 34 (1913).

chosen between the yield and the maximum strength. This constituted the original program, but on account of some unexpected results obtained in the tests, it seemed necessary to add three more overstraining loads. The first, in which the specimens were overstrained just to the yield; the second, in which the specimens were overstrained just through the yield; and the third, in which the specimens were overstrained to the maximum load.

Next, for the variable time series, 28,000 pounds, or 91,250 pounds per square inch, was adopted as the load to which to stress the specimens. Four different periods of rest were chosen, namely, twenty minutes, one week, two weeks, and four weeks.

SPECIMENS.

The specimens used in these tests were prepared at the Watertown Arsenal. Their chemical composition was as follows:

	Per cent.
Carbon	.45
Manganese	.48
Silicon	.09
Sulphur	.035
Phosphorus	.035
Nickel	3.20

They were $\frac{5}{8}$ inch in diameter with $1\frac{1}{4}$-inch screwed ends, the distance between the shoulders being long enough to accommodate apparatus set on a 10-inch gage length.

All the specimens were annealed by heating to 825° C. in a semi-muffle furnace. They were held at the annealing temperature for one hour and allowed to cool slowly with the furnace.

APPARATUS.

The machine used for the tests was the 100,000-pound Riehle in the testing laboratory of the Massachusetts Institute of Technology.

The extensometers used were slightly different from the usual type. From the standpoint of accuracy, the readings of elongations must be divided into two groups—those up to the yield point, and those from the yield to the rupturing of the specimen.

First to be considered is the method used in taking readings up to the yield point. Inasmuch as an accurate determination of the stress-strain diagram up to the yield point was necessary in order to detect changes in the elastic limit and modulus of elasticity, it was essential to find some method of reading elongations to one ten-thousandths of an inch or better. The ordinary 8-inch micrometer extensometers were clearly not to be considered. The precision micrometer extensometers, arranged with an electric contact device, are very similar to the above, but the required accuracy could undoubtedly be obtained with them. However, besides the need of great accuracy, it seemed quite essential that an extensometer be used which could be read more quickly than the micrometer type. To this end, some experiments with Berry extensometers were made. In order to obtain the desired accuracy, it was necessary that the instruments be mechanically fastened to the specimen, and a method of doing this was adopted. This arrangement allowed of freedom from contact throughout a test, and all liability of error due to personal equation in making adjustments was eliminated. Figures 1 and 2 show the

method of attachment. A slotted strip of steel, screwed snugly to the frames of the instruments, holds them tightly in place against the specimen. The small holes into which the Berry extensometer points fit are made with a No. 55 drill. In order to avoid drilling holes in the specimens for the location of the points, two split collars were prepared which could be attached to the specimens and the holes drilled in these.

The collars and specimens were carefully indexed so that it was possible to have the Berry instruments diametrically opposite and in the same plane. The collars were made so that a surface one-eighth inch wide was in contact with the specimen. As they were made to fit the specimens in their annealed condition, it became necessary to place cardboard shims under them when testing the specimens which had been overstrained enough to make an appreciable decrease in their diameter.

In order to get some idea of the accuracy of this Berry extensometer arrangement, the following experiment was made: The Berry extensometers were attached to a specimen of machine steel, and to the same specimen was attached a 16-inch precision electric micrometer extensometer. A load of 5,000 pounds was applied, and zero settings were made on the extensometers. A load of 15,000 pounds was then applied and readings taken, after which the load was decreased to 5,000 pounds and readings were again taken. This operation was repeated four times, and the results appear in the following tables:

Calibration of Berry extensometers.

SPECIAL STEEL BAR 1½-INCH DIAMETER.

BERRY EXTENSOMETERS, 8-INCH GAUGE LENGTH.

Load.	Left.	Right.	Average.	Difference.
Pounds.	*Inch.*	*Inch.*	*Inch.*	*Inch.*
5,000	0.00000	0.00000	0.00000	.....
15,000	.00325	.00330	.00327	0.00327
5,000	−.00020	.00030	.00005	.....
15,000	.00310	.00350	.00330	.00325
5,000	−.00020	.00030	.00005	.....
15,000	.00307	.00350	.00329	.00324
5,000	−.00015	.00030	.00007	.....
15,000	.00310	.00350	.00330	.00323
Total	.....	.....	.....	.01299
Average difference	.....	.....	.....	.003248

PRECISION ELECTRIC MICROMETER EXTENSOMETERS, 16-INCH GAUGE LENGTH.

Load.	Left.	Right.	Sum.	Average.	Difference.	Difference. 2
Pounds.	*Inch.*	*Inch.*	*Inch.*	*Inch.*	*Inch.*	
5,000	0.2752	0.2238	0.4990	0.2495	.....	.....
15,000	.2684	.2176	.4860	.2430	0.0065	0.00325
5,000	.2744	.2246	.4990	.2495	.....	.....
15,000	.2679	.2178	.4857	.24285	.00665	.003325
5,000	.27450	.22440	.49890	.24945	.....	.....
15,000	.26795	.21785	.48580	.24290	.00655	.003275
5,000	.27455	.22425	.49880	.24940	.....	.....
15,000	.26795	.21780	.48575	.24287	.00653	.003265
Total....	.....	.....	.....	.....	.02623	

16-inch gage, average difference.....inch.. 0.006558
8-inch gage, average difference.....do.... .003279

In discussing the results it must be kept in mind that the Berrys have an 8-inch gauge length, while the precision electric extensometer has a 16-inch gauge length. The Berry dial reads directly to 0.0002 inch, and if read carefully, should enable one to estimate to 0.00005 inch. The micrometer heads on the precision extensometer read directly to 0.0001 inch, and can be estimated to 0.00002 inch. But to offset the apparent advantage of the latter, is the fact that the personal error introduced in the adjusting of the micrometers is avoided in the case of the Berrys. In order to have a definite basis for comparison, assume that the average difference as obtained by the precision instruments is correct. Now, in comparing with this the results as obtained with the Berrys, we find the average difference as obtained with the Berrys, is 0.00003 inch (0.003279 − 0.003248 inch) less than that obtained by the precision instrument. However, as before mentioned, the Berrys can not be read to better than 0.00005 inch. This means that there are no calibration corrections to be applied to the Berry readings.

In the test proper, it will be seen that the mean of each pair of Berry readings has been multiplied by $\frac{4}{5}$ in order to change the readings to a 10-inch gauge length. This was done that the results might be compared with certain others. No error has been introduced by so doing, inasmuch as it is safe to assume that up to the elastic limit the specimen will elongate uniformly.

The next readings to be considered are those beyond the yield point. In adopting a measuring device for these readings, accuracy takes second place, as readings to 0.01 inch are sufficiently accurate; and, therefore, the important thing to bear in mind is the advantage of a simple attachment which can be read with great rapidity. The scale extensometer adopted really needs little explanation, as it can be quite clearly seen in the photographs Figs. 1 and 2 of the Appendix. It was always set on a 10-inch gauge length in these tests.

DESCRIPTIONS OF TESTS.

In overstraining the specimens the load was applied by power feed nearly to the elastic limit. From there on it was applied carefully by hand, in order to obtain the yield point accurately. Then the power feed was immediately applied again, at the rate of 0.25 inch per minute, and the specimen stressed to the required load. Whereupon the machine was immediately reversed until the load was removed, and the specimen was then taken out.

TEST PROPER.

As soon as the specimen was in position in the machine, the Berry extensometers and the scale apparatus were attached. The machine was then balanced, and an initial load of 1,000 pounds put on. The Berry dials were now set at zero and the scale set so that 2 inches was opposite the reference point. An additional load was now applied and the Berry instruments read. In this way readings were taken all the way up to the yield point, the loads being added by hand to the yield point.

When the yield point was reached, the Berry extensometers were quickly removed, and the load applied by power feed, at the rate of

0.25 inch per minute, until the specimen was ruptured. Up to the elastic limit the time element naturally does not affect the results. From the time that the power feed is thrown in until the specimen is ruptured, the same conditions exist for all tests. That leaves one variable period in the tests which could not be eliminated entirely—namely, the time elapsing between the moment the elastic limit is passed and the power feed is thrown in. Several of the tests were carefully timed, but no noticeable effects which could be attributed to the slight variations in time during the above-mentioned period, were found.

RESULTS.

The results of the tests in the form of summary data and plots appear on the pages immediately following.

The data and corresponding stress-strain diagram for each test will be found in the Appendix.

Annealed condition.

Group.	Specimen No.	Original diameter (inch).	Initial load (pounds).	Original yield (pounds).	Period of rest.	New diameter (inch).	Elastic limit (pounds per square (inch).	Average elastic limit (pounds).	Yield point (pounds per square inch).
A 1	12	0.6255	.....	18,200	.....	.....	54,400	55,600	59,300
2	24	.6250	.....	18,200	.....	.....	55,400		59,100
3	27	.6255	.....	18,400	.....	.....	57,000		59,800

Group.	Average yield point (pounds).	Maximum load (pounds per square inch).	Average maximum load.	Modulus of elasticity (pounds per square inch).	Hypoelastic work (foot pounds per square inch of specimen).	Total work of rupture (foot pounds per square inch).	Diameter of fractured section (inch).	Reduction in area (per cent).	Elongation (per cent).
A 1	59,500	101,600	100,000	29,300,000	42.2	13,430	0.4385	50.9	17.5
2		99,100		28,900,000	44.0	14,000	.433	52.2	18.5
3		99,300		29,300,000	45.8	13,250	.430	52.8	17.6

Overstrained condition.

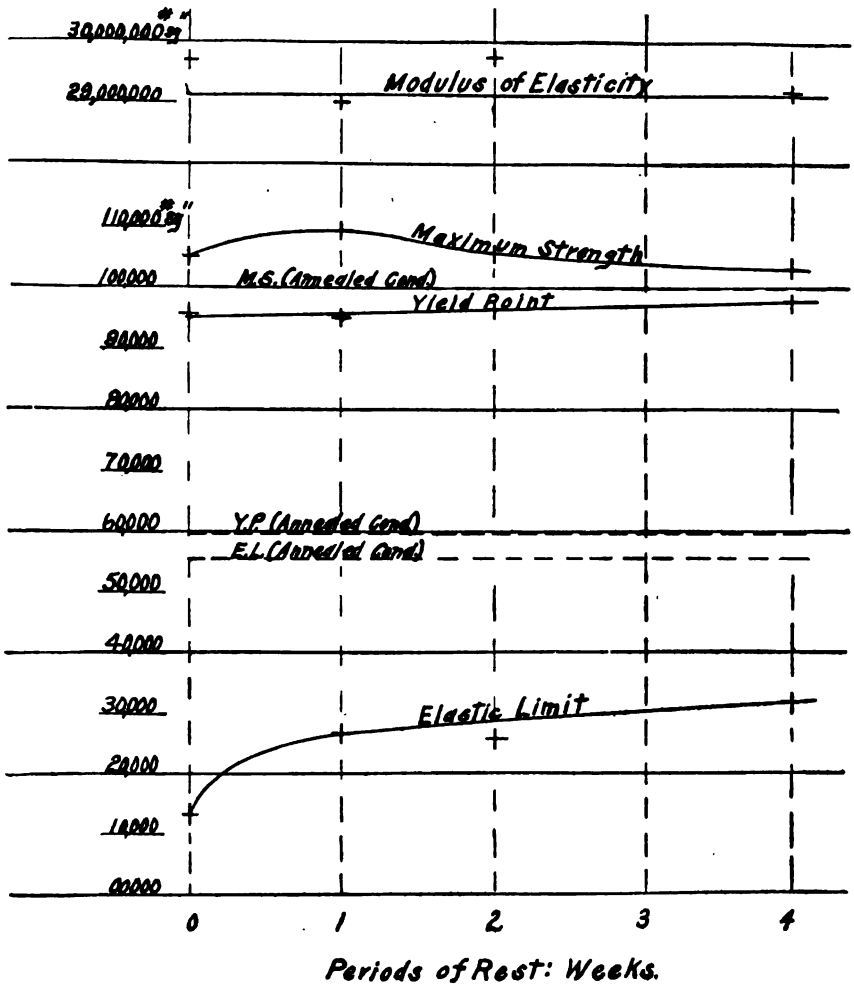
VARIABLE TIME SERIES.

I 1	13	0.6255	28,000	19,600	20 min.	0.6150	14,150	13,300	94,300
2	14	.6250	28,000	18,000	...do....	.6060	12,500		97,100
F 1	5	.6230	28,000	18,500	1 week.	.6115	27,250	26,450	95,500
2	7	.6260	28,000	18,800	...do.....	.6125	25,150		95,100
3	8	.6260	28,000	18,800	...do.....	.6150	25,900		94,300
4	11	.6250	28,000	19,200	...do.....	.6160	27,500		94.700
J 1	6	.6250	28,000	17,500	2 weeks.	.6067	25,250	25,500	97,600
2	9	.6250	28,000	19,800	...do.....	.6130	25,750		95,700
K 1	4	.6250	28,000	18,000	4 weeks.	.6090	31,600	32,000	97,500
2	10	.6255	28,000	18,200	...do.....	.6077	32,400		98,000

I 1	95,700	106,800	105,000	29,500,000	2.85	11,100	0.451	46.3	12.9
2		101,300		29,950,000	2.13	7,300	.434	48.7	9.0
F 1	94,900	108,400	109,300	28,700,000	10.68	9,000	.452	45.5	10.3
2		106,700		28,900,000	9.01	9,800	.445	47.2	11.4
3		108,700		29,400,000	9.50	12,700	.456	45.0	14.5
4		113,500		28,800,000	10.90	9,600	.476	40.5	10.4
J 1	96,650	103,400	105,700	29,600,000	8.83	9,400	.435	48.7	11.3
2		108,000		29,900,000	9.30	10,500	.447	47.0	12.5
K 1	97,750	103,700	103,200	28,950,000	14.33	9,000	.435	49.0	11.0
2		102,700		29,400,000	14.87	8,700	.429	50.3	10.7

EFFECTS OF OVERSTRAIN—VARIABLE TIME SERIES.

Initially loaded to 28,000 pounds. (91,200 pounds per square inch.)
Average original yield, 18,800 pounds.
Period of rest, variable, as indicated.
Specimens, nickel steel, ⅝ inch in diameter.
Gage length, 10 inches.



Overstrained condition.

VARIABLE OVERSTRAIN SERIES.

Group.	Specimen No.	Original diameter (inch).	Initial load (pounds).	Original yield (pounds).	Period of rest.	New diameter (inch).	Elastic limit (pounds per square inch).	Average elastic limit (pounds).	Yield point (pounds per square inch.)
B 1....	15	0.6250	To yield.	18,800	1 week..	0.6250	54,750	56,000	57,300
2....	16	.6260	...do.....	19,800	...do.....	.6255	57,300		60,600
C 1....	28	.6250	Through yield.	18,800	...do.....	.6223	24,350	26,100	65,200
2....	29	.6210	...do.....	19,200	...do.....	.6188	27,900		65,800
D 1....	17	.6255	20,000	17,000	...do.....	.6218	26,400		65,800
2....	22	.6255	20,000	19,600	...do.....	.6232	26,900	26,600	66,800
3....	23	.6250	20,000	19,200	...do.....	.6214	26,400		66,000
E 1....	18	.6255	24,000	18,800	...do.....	.6170	29,400		80,300
2....	25	.6255	24,000	18,000	...do.....	.6158	27,500	27,800	81,300
3....	26	.6250	24,000	19,200	...do.....	.6182	26,700		80,000
F 1....	5	.6230	28,000	18,500	...do.....	.6115	27,250		95,500
2....	7	.6260	28,000	18,800	...do.....	.6125	25,150	26,450	95,100
3....	8	.6260	28,000	18,800	...do.....	.6150	25,900		94,300
4....	11	.6250	28,000	19,200	...do.....	.6160	27,500		94,700
G 1....	19	.6265	30,000	20,000	...do.....	.6105	25,950		102,500
2....	20	.6255	30,000	19,200	...do.....	.6093	24,000	24,500	103,000
3....	21	.6250	30,000	19,000	...do.....	.6150	23,600		101,000
H 1....	30	.6250	[1] 31,000	19,000	...do.....	.6000	26,800	26,800	109,500

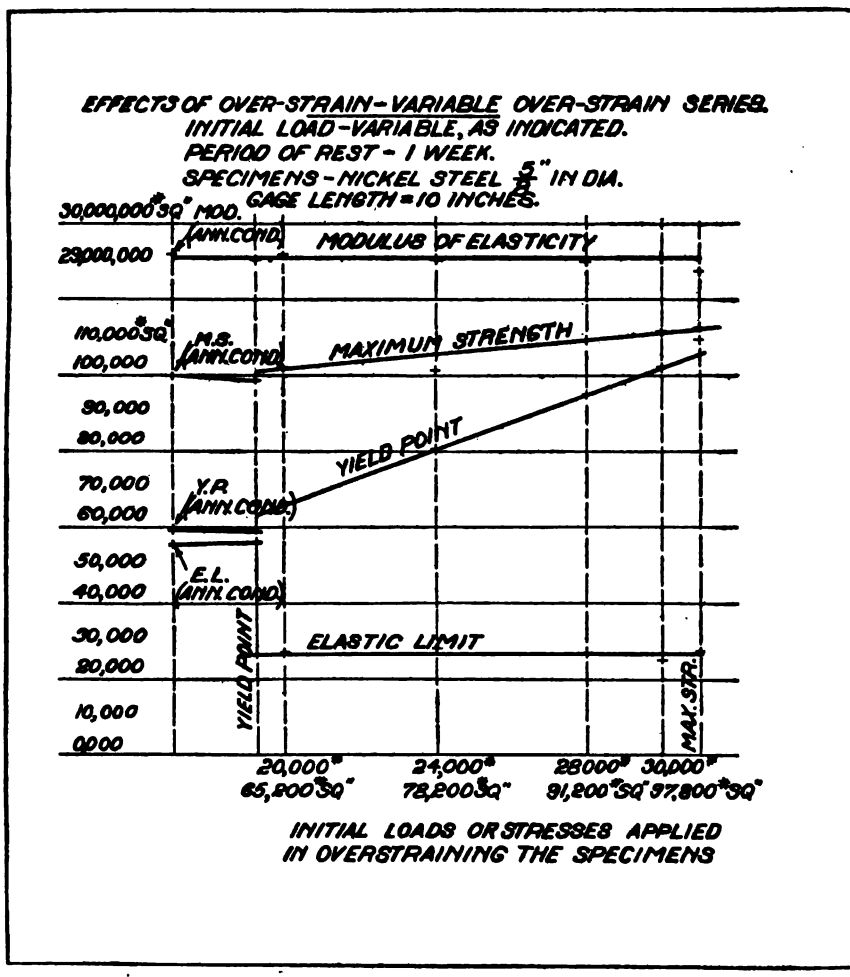
Group.	Average yield point (pounds).	Maximum load (pounds per square inch).	Average maximum load.	Modulus of elasticity (pounds per square inch).	Hypoelastic work (foot-pounds per square inch of specimen).	Total work to rupture (foot-pounds per square inch).	Diameter of fractured section (inches).	Reduction in area (per cent).	Elongation (per cent).
B 1....	59,000	96,100	98,750	29,000,000	43.10	12,200	0.426	53.5	16.8
2....		101,400		29,200,000	47.00	12,800	.438	51.2	16.8
C 1....	65,500	105,100	105,700	28,900,000	8.60	10,600	.451	47.5	15.4
2....		106,300		29,100,000	11.15	12,600	.455	46.0	15.5
D 1....	66,300	97,600	102,100	28,900,000	10.00	10,200	.436	50.8	13.7
2....		108,400		29,400,000	10.28	11,800	.467	43.9	14.2
3....		100,400		29,200,000	9.90	14,700	.433	51.5	18.7
E 1....	80,500	100,400	101,300	29,100,000	12.25	13,300	.430	51.5	16.8
2....		98,800		29,100,000	10.80	12,900	.419	53.7	16.5
3....		104,700		28,850,000	10.18	11,750	.438	49.7	14.3
F 1....	94,900	108,400	109,300	28,700,000	10.68	9,000	.452	45.5	10.3
2....		106,700		28,900,000	9.01	9,800	.445	47.2	11.4
3....		108,700		29,400,000	9.50	12,700	.456	45.0	14.5
4....		113,500		28,800,000	10.90	9,600	.476	40.5	10.4
G 1....	102,200	109,700	111,600	29,300,000	9.57	10,800	.456	44.3	12.2
2....		109,400		29,200,000	8.24	10,700	.445	46.7	12.3
3....		115,700		28,800,000	8.03	10,600	.500	34.0	11.4
H 1....	109,500	112,500	112,500	28,700,000	10.50	7,100	.455	42.8	8.0

[1] Maximum.

DISCUSSION.

Although there is a diversity of opinion as to the effects of tensile overstrain, according to James Muir,[1] it seems to have been more or less generally known for some time that the ultimate effect of such treatment is to raise the elastic limit. The article goes on to say:

More recently, however, attention has been called to the fact that primarily the result of tensile overstrain is to make the iron assume a semiplastic state; so that the



elastic limit, instead of being raised by stretching, is first of all lowered, it may be, to zero. * * * It is the recovery from this semiplastic state, induced by overstrain, to a condition of perfect or nearly perfect elasticity, with raised elastic limit, that is referred to in the title of the paper of which this is an abstract. Such recovery is known to be affected by mere lapse of time, and * * *

Recovery is shown to be at first comparatively rapid; but subsequently very slow progress is made, and weeks or months may be required before an approximately

[1] Abstract communicated by Prof. Ewing. Proc. Royal Soc. (1898-9), vol. 64, page 337.

perfect restoration of elasticity is effected. When this is brought about, the specimen may be subjected to a stress a few tons per square inch higher than that at which the virgin material yielded, before a yield point is passed and the material once more brought into a semiplastic state.

Turning to the results of the present tests in which the period of rest was varied, it is quickly seen that they agree very nicely with the above statements. A specimen overstrained and immediately tested has a very low, but still a definite elastic limit. As the period of rest is increased it is seen that the elastic limit rises quickly at first, but more gradually as time goes on. It is impossible to state just how long a period of rest would be necessary in order that the elastic limit of the specimen regain its original value.

Unwin [1] quotes some results from Bauschinger and draws up the following conclusions:

If a material is strained to or beyond the yield point, unloaded, and again immediately loaded—

(*a*) The breaking extension is diminished and the breaking load somewhat decreased.

(*b*) The elastic limit is lowered, sometimes to zero, and the modulus of elasticity is a little diminished.

(*c*) The yield point is raised to the stress corresponding to the previous load.

If, after the first loading, a period of quiescence is allowed before the second loading—

(*d*) The elastic limit rises sometimes above its initial value.

(*e*) The yield point rises gradually above the stress corresponding to the previous load.

Again looking at the results of the present tests, there is evidently a slight disagreement in that in these tests the modulus of elasticity apparently increases rather than decreases a small amount in one or two cases. Yet, although the data shows these small increases in the modulus of elasticity, it looks as if the modulus really does not change, but that the elastic limits were very low and there were too few points taken to enable the true line to be drawn. In the present tests it was also found that the material had to be stressed through rather than to the yield point before any very noticeable effects were produced. The results of the variable time series in so far as they were carried out agree closely with the rest of the above statements.

CONCLUSIONS.

(*a*) If a material is stressed beyond its elastic limit but only to the yield point and is then rested a week and reloaded—

(1) The elastic limit is apparently unaffected, the yield point and maximum strength are either not affected at all or are only very slightly lowered, the modulus of elasticity is unchanged, and apparently the period of rest has not played an important part.

(*b*) If a material is stressed through or beyond its yield point and is then allowed to rest for one week and reloaded—

(1) The elastic limit is found to be a little less than half of its original value and apparently remains constant for varying amounts of overstrain up to and including the maximum load.

(2) The yield point is raised to the stress corresponding to the overstraining load.

(3) The maximum or tensile strength is raised slightly, the amount increasing with the increase of the overstraining load.

[1] Testing of materials of construction, Ch. V, p. 118.

(*c*) If a material is stressed through or beyond its elastic limit and then reloaded, the period of rest being made a variable, it is found that—

(1) Immediately after overstraining the elastic limit is about one-fourth of its original value, but increases rapidly at first and then more gradually as time goes on. No conjecture as to the lapse of time necessary before it will recover its original value, or, for that matter, whether it will ever fully recover, can here be made, owing to the limited extent of the test.

(2) The yield point, as before stated, is raised to the stress corresponding to the previous overstraining load. Increase in the period of rest increases it very slightly.

(3) The maximum strength immediately after overstrain is a little higher than its original value in the annealed condition and rises somewhat during the first week of rest. Apparently, however, from then on it decreases gradually.

APPENDIX.

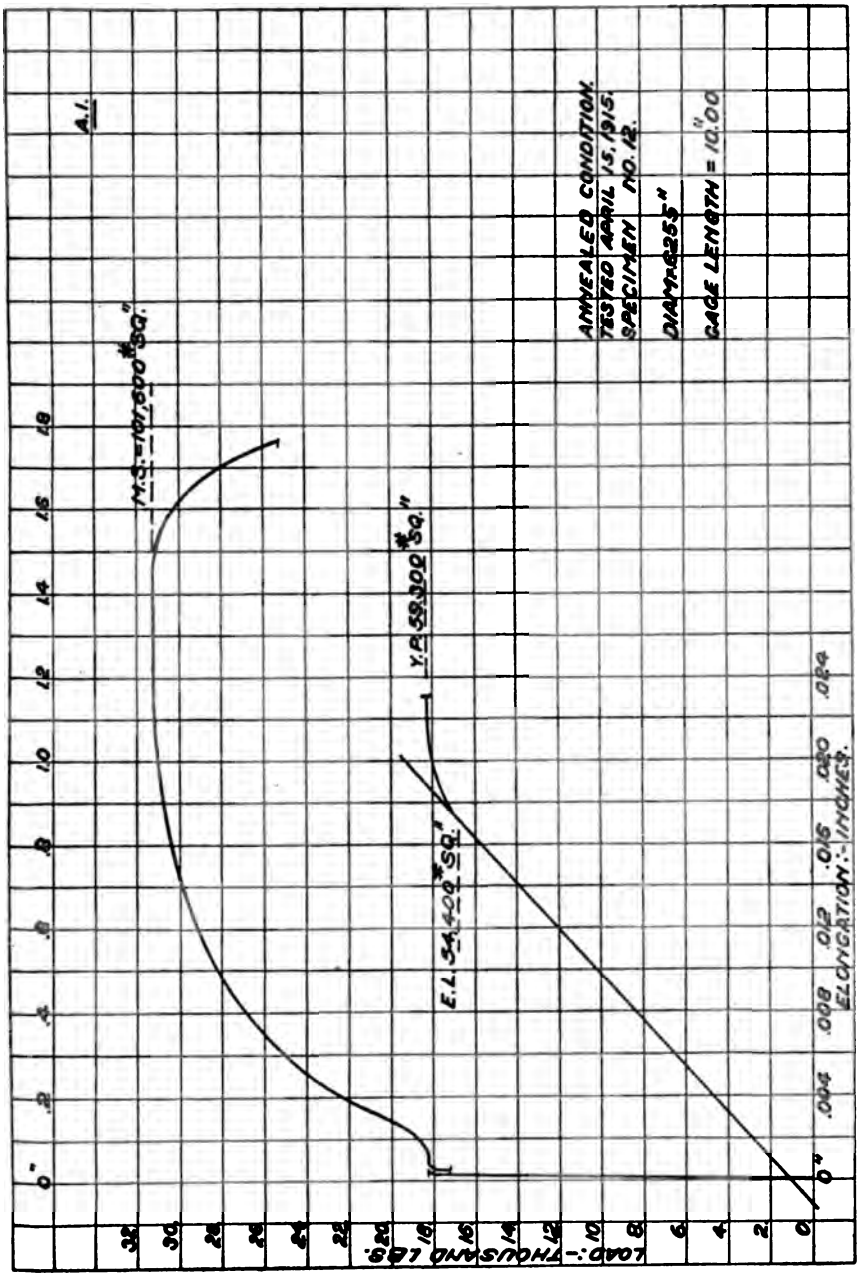
The data and corresponding stress-strain diagram for each test appear on the following pages:

Test.	Pages.	Test.	Pages.
Group A 1	130	Group F 2	158
2	132	3	160
3	134	4	162
B 1	136	G 1	164
2	138	2	166
C 1	140	3	168
2	142	H 1	170
D 1	144	I 1	172
2	146	2	174
3	148	J 1	176
E 1	150	2	178
2	152	K 1	180
3	154	2	182
F 1	156		

SPECIMEN NO. 12, GROUP A 1.

Annealed.

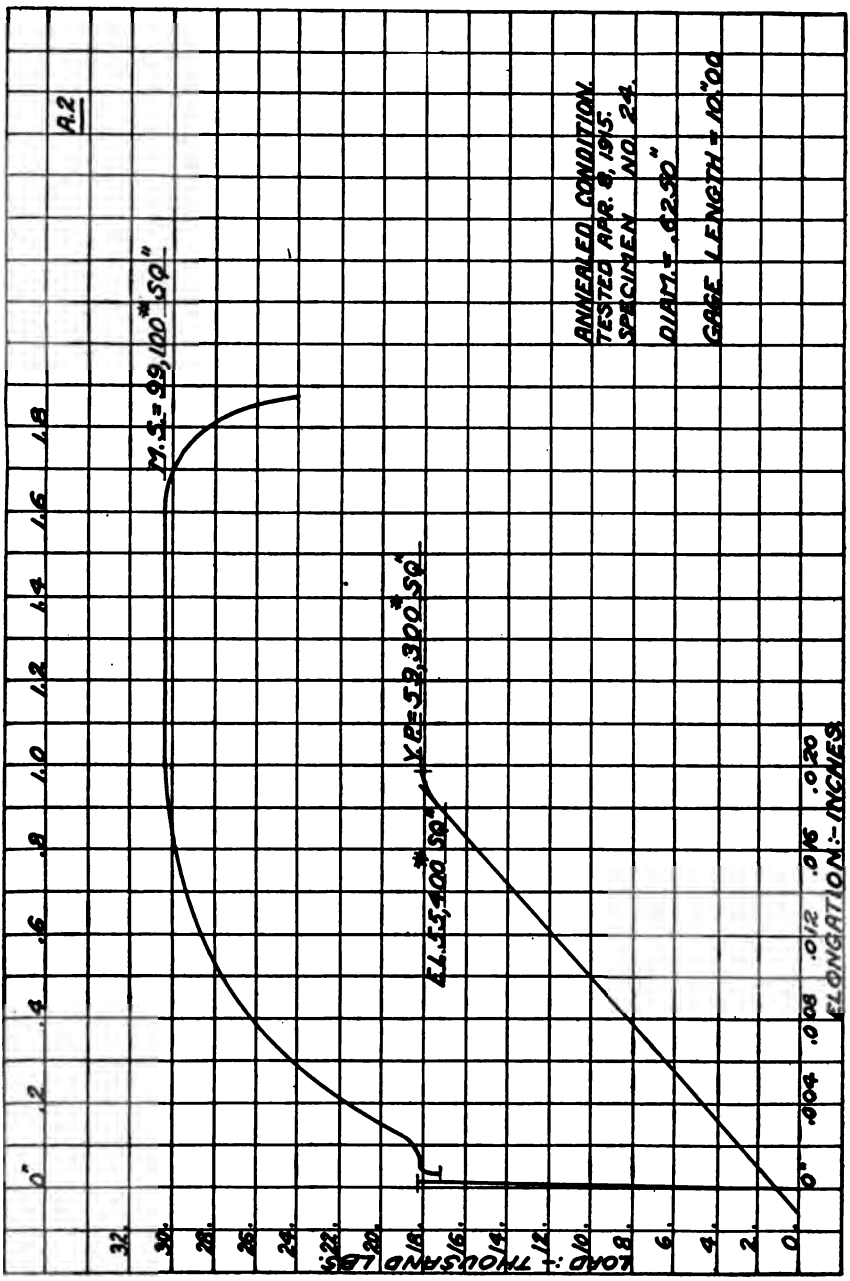
Load.	Extensometers.			
	Left.	Right.	Mean.	
			8-inch gauge.	10-inch gauge.
Pounds.	*Inch.*	*Inch.*	*Inch.*	*Inches.*
1,000	0.00000	0.00000	0.00000	0.00000
2,000	.00090	.00080	.00085	.00106
3,000	.00180	.00165	.00172	.00216
4,000	.00265	.00250	.00257	.00322
5,000	.00345	.00340	.00342	.00428
6,000	.00430	.00430	.00430	.00538
7,000	.00515	.00520	.00517	.00646
8,000	.00595	.00610	.00602	.00781
9,000	.00685	.00705	.00695	.00869
10,000	.00780	.00790	.00785	.00981
11,000	.00870	.00885	.00877	.01096
12,000	.00960	.00970	.00965	.01206
13,000	.01050	.01060	.01055	.01319
14,000	.01140	.01150	.01145	.01431
15,000	.01230	.01250	.01240	.01550
16,000	.01320	.01340	.01330	.01663
17,000	.01420	.01430	.01425	.01781
17,600	.01480	.01490	.01485	.01856
18,200	.01860	.0183	.01845	.02306
				Scale reading.
17,200	.....	.....	.....	0.03
18,000	.....	.....	.....	.03
19,000	.....	.....	.....	.12
20,000	.....	.....	.....	.16
21,000	.....	.....	.....	.17
22,000	.....	.....	.....	.18
23,000	.....	.....	.....	.22
24,000	.....	.....	.....	.26
25,000	.....	.....	.....	.30
26,000	.....	.....	.....	.35
27,000	.....	.....	.....	.41
28,000	.....	.....	.....	.48
29,000	.....	.....	.....	.58
30,000	.....	.....	.....	.73
30,500	.....	.....	.....	.85
30,750	.....	.....	.....	.97
31,000	.....	.....	.....	1.14
31,200	.....	.....	.....	1.30
30,000	.....	.....	.....	1.62
28,000	.....	.....	.....	1.70
26,000	.....	.....	.....	1.75
25,000	.....	.....	.....	.....


A.1.
ANNEALED CONDITION.
TESTED APRIL 15, 1915.
SPECIMEN NO. 12.
DIAM. 0.255"
GAGE LENGTH = 10.00"
M.S. = 101,600 #/SQ."
Y.P. 59,300 #/SQ."
E.L. 34,400 #/SQ."
LOAD :- THOUSAND LBS.
ELONGATION :- INCHES.

SPECIMEN NO. 24, GROUP A 2.

Annealed.

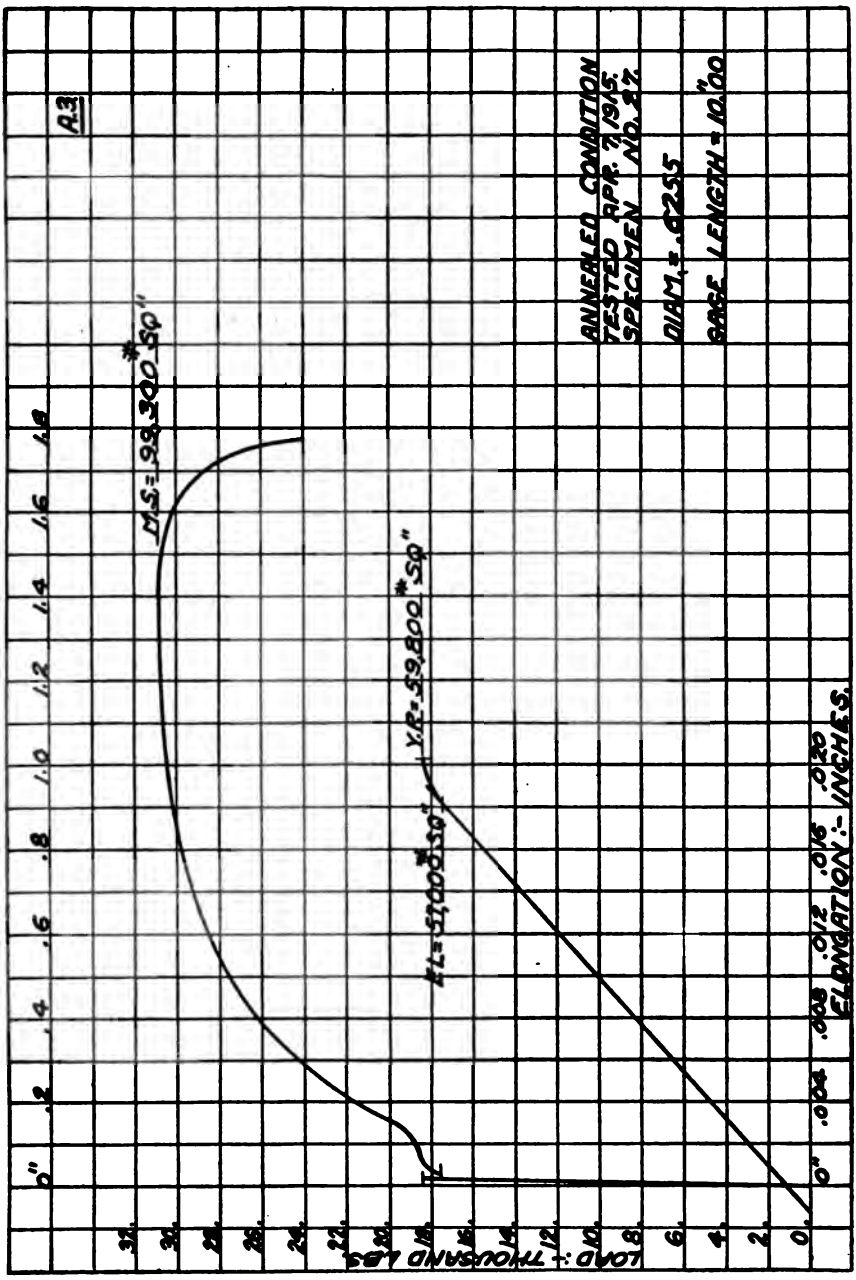
Load.	Extensometers.			
	Left.	Right.	Mean.	
			8-inch gauge.	10-inch gauge.
Pounds.	*Inch.*	*Inch.*	*Inch.*	*Inch.*
1,000	0.00000	0.00000	0.00000	0.00000
2,000	.00080	.00070	.00075	.00094
4,000	.00255	.00250	.00253	.00316
6,000	.00430	.00430	.00430	.00538
8,000	.00615	.00615	.00615	.00769
10,000	.00790	.00795	.00793	.00991
12,000	.00960	.00980	.00970	.01213
14,000	.01150	.01150	.01150	.01438
16,000	.01335	.01330	.01333	.01666
16,500	.01380	.01380	.01380	.01725
17,000	.01430	.01425	.01428	.01785
17,400	.01470	.01455	.01463	.01829
17,800	.01520	.01505	.01513	.01891
18,200	.01600	.....	.0160	.02000
				Scale reading.
17,100	.....	.....	.....	0.03
18,000	.....	.....	.....	.04
19,000	.....	.....	.....	.13
20,000	.....	.....	.....	.15
22,000	.....	.....	.....	.22
24,000	.....	.....	.....	.30
26,000	.....	.....	.....	.39
28,000	.....	.....	.....	.55
29,000	.....	.....	.....	.68
30,000	.....	.....	.....	.88
30,400	.....	.....	.....	.....
30,400	.....	.....	.....	.....
30,000	.....	.....	.....	1.70
29,000	.....	.....	.....	1.78
24,000	.....	.....	.....	1.89


A.2
M.S.= 99,100 #/SQ"
ANNEALED CONDITION.
TESTED APR. 8, 1915.
SPECIMEN NO. 24.
DIAM.= .2530"
GAGE LENGTH = 10.00
E = 13,300 #/SQ"
E = 13,400 #/SQ"
LOAD :- THOUSAND LBS.
ELONGATION:- INCHES
0" .2 .4 .6 .8 1.0 1.2 1.4 1.6 1.8
32. 30. 28. 26. 24. 22. 20. 18. 16. 14. 12. 10. 8. 6. 4. 2. 0.
0" .004 .008 .012 .016 .020

SPECIMEN NO. 27, GROUP A 3.

Annealed.

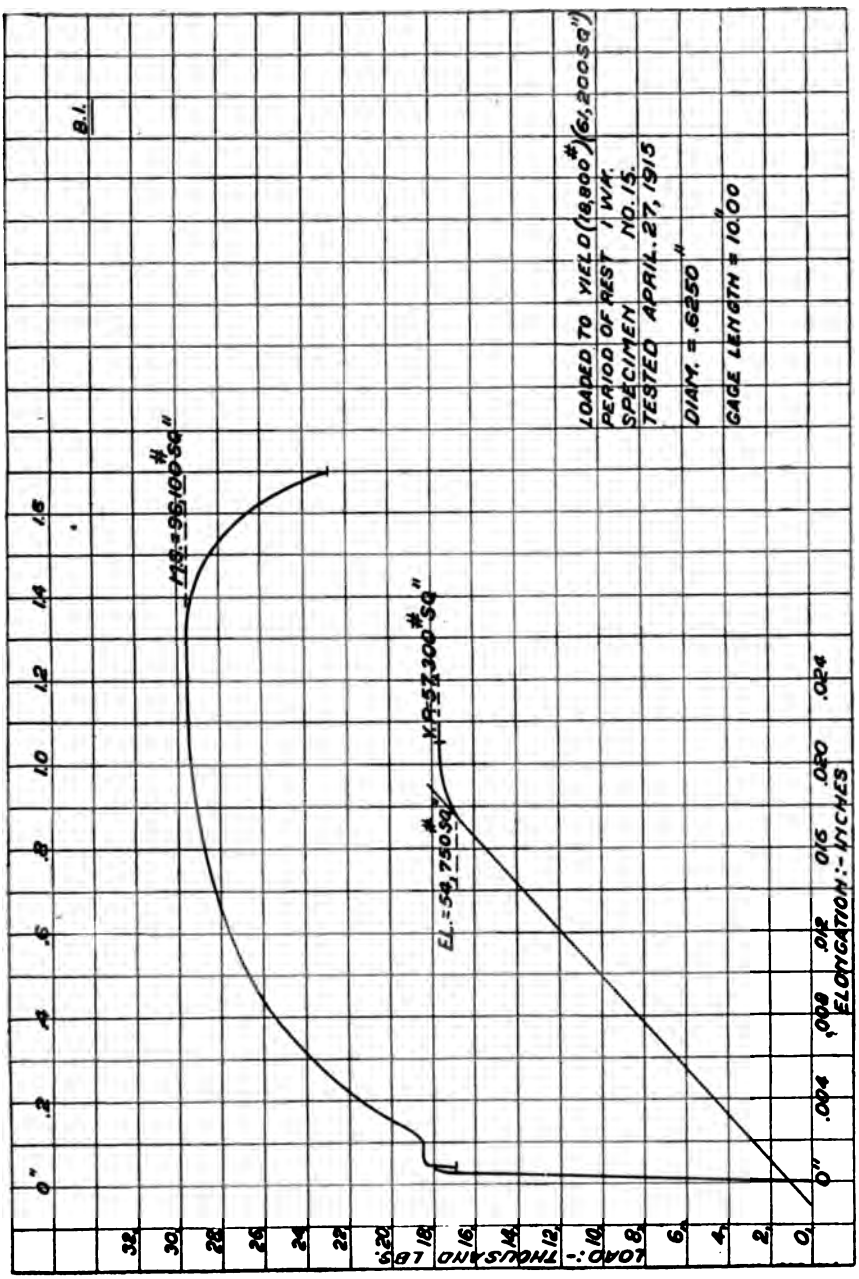
Load.	Extensometers.			
	Left.	Right.	Mean.	
			8-inch gauge.	10-inch gauge.
Pounds.	*Inch.*	*Inch.*	*Inch.*	*Inch.*
1,000	0.00000	0.00000	0.00000	0.00000
2,000	.00085	.00105	.00095	.00119
4,000	.00260	.00270	.00265	.00331
6,000	.00430	.00440	.00435	.00544
8,000	.00600	.00625	.00613	.00766
10,000	.00785	.00805	.00795	.00994
12,000	.00955	.00980	.00968	.01210
14,000	.01135	.01165	.01150	.01438
16,000	.01320	.01340	.01330	.01663
16,500	.01365	.01390	.01378	.01722
17,000	.01410	.01435	.01423	.01779
17,500	.01460	.01470	.01465	.01831
18,000	.01530	.01520	.01525	.01906
18,500	.....	.....	.....	.....
				Scale reading.
17,500	.....	.....	.....	0.03
19,000	.....	.....	.....	.13
.....	.....	.....	.....	.20
25,000	.....	.....	.....	.34
27,000	.....	.....	.....	.47
28,000	.....	.....	.....	.55
29,000	.....	.....	.....	.69
30,000	.....	.....	.....	.94
30,500	.....	.....	.....	.....
30,500	.....	.....	.....	.....
30,000	.....	.....	.....	1.60
29,000	.....	.....	.....	1.69
26,000	.....	.....	.....	1.75
24,000	.....	.....	.....	.....


A3
ANNEALED CONDITION
TESTED APR. 7, 1915.
SPECIMEN NO. 12
DIAM. = .6255
GAGE LENGTH = 10.00"
M.S. = 99,300 #/SQ"
Y.P. = 59,800 #/SQ"
LOAD ÷ THOUSAND LBS.
ELONGATION :- INCHES.

SPECIMEN NO. 15, GROUP B 1.

Loaded to yield (18,800 pounds).
Period of rest one week.

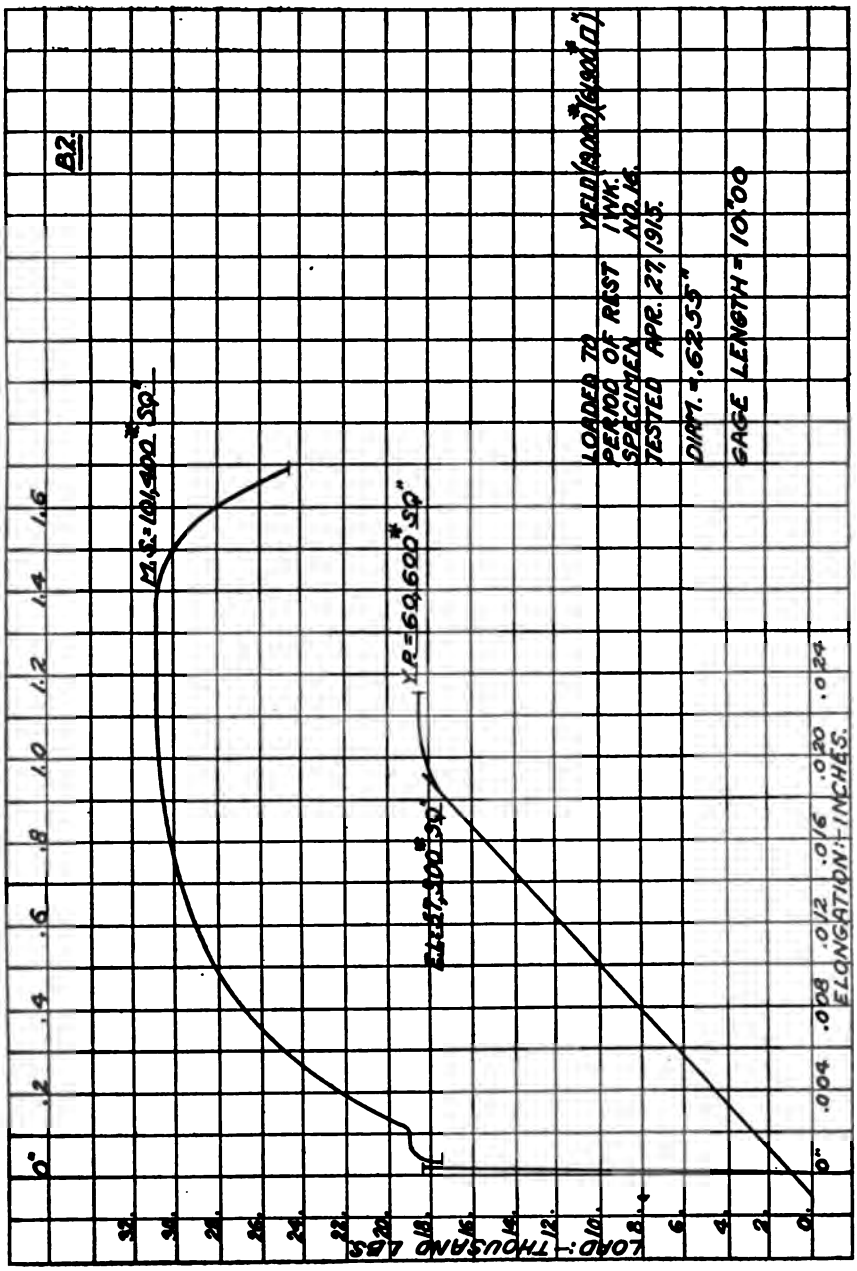
Load.	Extensometers.			
	Left.	Right.	Mean.	
			8-inch gauge.	10-inch gauge.
Pounds.	*Inch.*	*Inch.*	*Inch.*	*Inch.*
1,000	0.00000	0.00000	0.00000	0.00000
2,000	.00110	.00075	.000931	.00116
3,000	.00230	.00130	.00180	.00225
4,000	.00345	.00195	.00270	.00337
5,000	.00435	.00280	.003575	.00447
6,000	.00520	.00350	.00435	.005435
7,000	.00620	.00440	.00530	.00663
8,000	.00710	.00525	.006175	.00772
9,000	.00800	.00620	.00710	.00888
10,000	.00900	.00715	.008075	.01009
11,000	.00980	.00800	.00890	.01113
12,100	.01080	.00900	.00990	.01237
13,000	.01160	.00990	.01075	.01344
14,000	.01250	.01090	.01170	.01463
15,000	.01340	.01180	.01260	.01575
16,000	.01425	.01270	.013475	.01684
17,000	.01500	.01380	.01440	.01800
17,600	.01780	.01580	.01680	.02100
				Scale reading.
18,000	.....	.....	.....	.045
17,000	.....	.....	.....	.045
18,000	.....	.....	.....	.05
18,500	.....	.....	.....	.....
19,000	.....	.....	.....	.13
21,000	.....	.....	.....	.19
23,000	.....	.....	.....	.27
25,000	.....	.....	.....	.38
26,000	.....	.....	.....	.45
27,000	.....	.....	.....	.53
28,000	.....	.....	.....	.66
29,000	.....	.....	.....	.87
29,500	.....	.....	.....	1.16
29,500	.....	.....	.....	1.30
29,300	.....	.....	.....	1.40
29,000	.....	.....	.....	1.50
27,000	.....	.....	.....	1.59
24,000	.....	.....	.....	1.68
23,000	.....	.....	.....	.....


B.L.
LOADED TO YIELD (18,800 #/(6,200 Sq")
PERIOD OF REST 1 WK.
SPECIMEN NO. 15.
TESTED APRIL. 27, 1915
DIAM. = .6250 "
GAGE LENGTH = 10.00 "
LOAD :- THOUSAND LBS.
ELONGATION :- INCHES
EL. = 56,750 #/Sq"
YP = 57,300 #/Sq"
TS = 95,100 #/Sq"

SPECIMEN NO. 16, GROUP B 2.

Loaded to yield (19,800 pounds).
Period of rest one week.

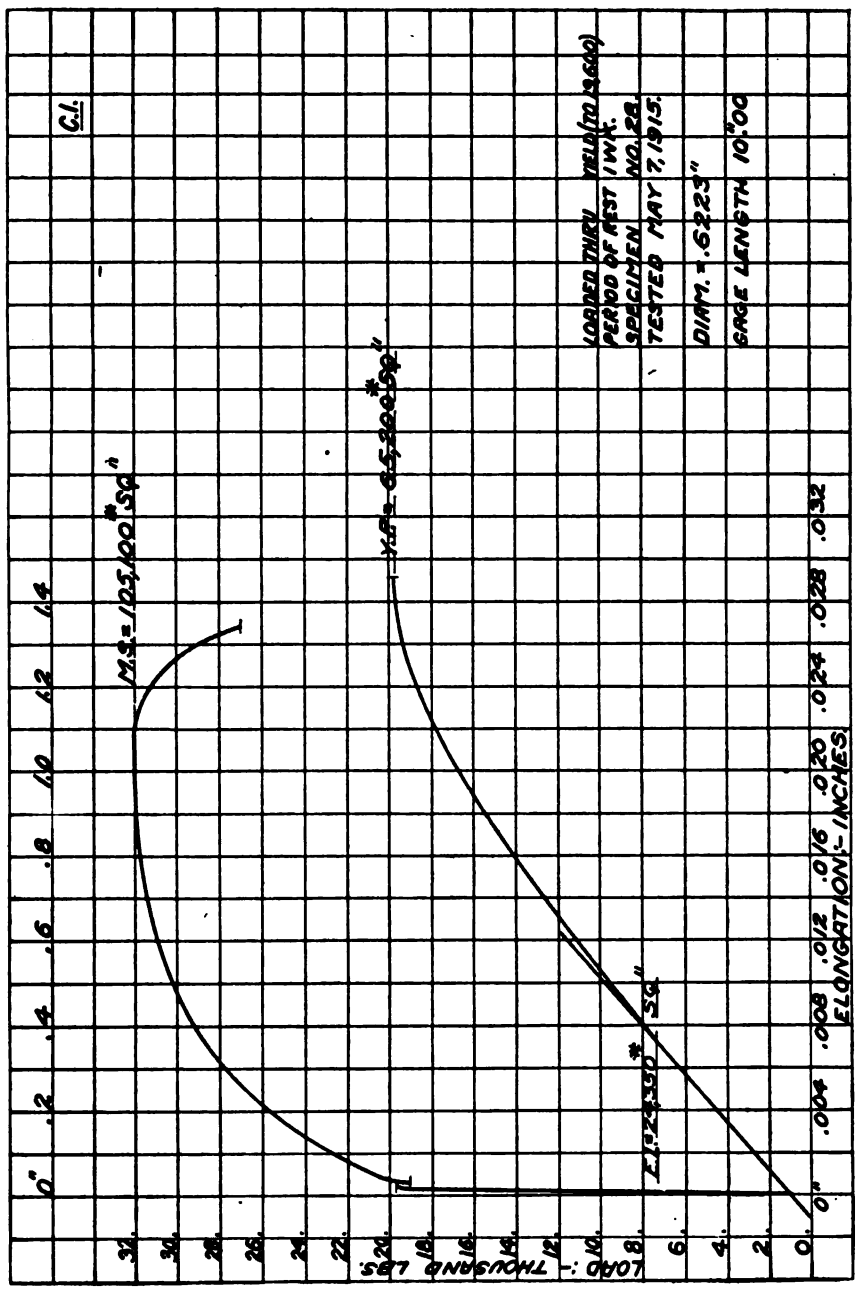
Load.	Extensometers.			
	Left.	Right.	Mean.	
			8-inch gauge.	10-inch gauge.
Pounds.	*Inch.*	*Inch.*	*Inch.*	*Inches.*
1,000	0.00000	0.00000	0.00000	0.00000
2,000	.00090	.00070	.00080	.00100
3,000	.00185	.00165	.00175	.00219
4,000	.00275	.00245	.00260	.00325
5,000	.00365	.00330	.003475	.00434
6,000	.00465	.00430	.004475	.00559
7,000	.00540	.00500	.00520	.00650
8,000	.00630	.00590	.00610	.00763
9,000	.00720	.00680	.00700	.00875
10,000	.00810	.00765	.007875	.00984
11,000	.00900	.00855	.008775	.01096
12,000	.00990	.00945	.009625	.01203
13,100	.01090	.01040	.01065	.01331
14,000	.01170	.01120	.01145	.01431
15,000	.01270	.01220	.01245	.01556
16,000	.01350	.01310	.01330	.01663
17,000	.01450	.01400	.01425	.01781
18,000	.01540	.01500	.01520	.01900
18,600	.0190	.01800	.01850	.02312
				Scale reading.
17,500	.....	.....	.....	.035
19,000	.....	.....	.....	.05
21,000	.....	.....	.....	.16
23,000	.....	.....	.....	.22
25,000	.....	.....	.....	.30
27,000	.....	.....	.....	.41
28,000	.....	.....	.....	.48
29,000	.....	.....	.....	.58
30,000	.....	.....	.....	.73
30,600	.....	.....	.....	.86
31,000	.....	.....	.....	1.06
31,140	.....	.....	.....	1.15
31,120	.....	.....	.....	1.35
30,000	.....	.....	.....	1.53
28,000	.....	.....	.....	1.61
24,700	.....	.....	.....	1.68


B2.
LOADED TO
PERIOD OF REST
SPECIMEN
TESTED APR. 27, 1915.
DIAM. = .6255"
GAGE LENGTH = 10"00
YIELD (LOAD/AREA)
/WK.
NO. 14.
LOAD :- THOUSAND LBS.
ELONGATION :- INCHES.

SPECIMEN NO. 28, GROUP C 1.

Loaded through yield (19,600 pounds).
Period of rest, one week.

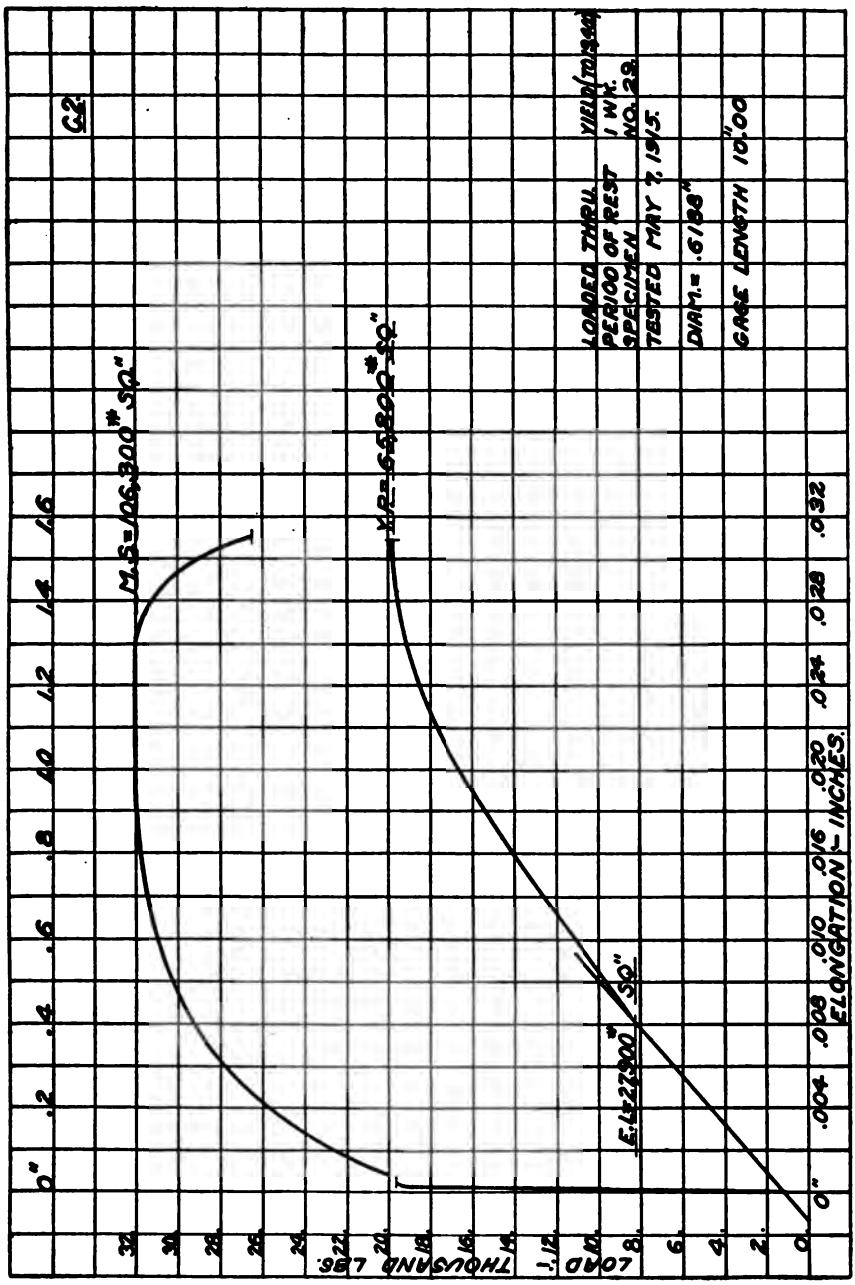
Load.	Extensometers.			
	Left.	Right.	Mean.	
			8-inch gauge.	10-inch gauge.
Pounds.	*Inch.*	*Inch.*	*Inch.*	*Inch.*
1,000	0.00000	0.00000	0.00000	0.00000
2,000	.00095	.00085	.00090	.00113
3,000	.00190	.00165	.001775	.00222
4,000	.00280	.00245	.002623	.00328
5,000	.00380	.00335	.003575	.00447
6,000	.00490	.00420	.00455	.00569
7,000	.00595	.00510	.005525	.00690
8,000	.00680	.00590	.00635	.00794
9,000	.00795	.00695	.00745	.00932
10,000	.00895	.00795	.00845	.01056
11,000	.01000	.00900	.00950	.01186
12,000	.01105	.01010	.010575	.01323
13,000	.01220	.01120	.01170	.01463
14,000	.01330	.01230	.01280	.01600
15,000	.01450	.01360	.01405	.01757
16,000	.01570	.01470	.01520	.01900
18,000	.01880	.01760	.01820	.02275
19,000	.02060	.01940	.02000	.02500
19,400	.0220	.0210	.0215	.02690
19,800	.0238	.0228	.0233	.02910
				Scale reading.
19,100	.....	.....	.....	.02
20,000	.....	.....	.....	.03
22,000	.....	.....	.....	.08
24,000	.....	.....	.....	.15
26,000	.....	.....	.....	.22
28,000	.....	.....	.....	.32
29,000	.....	.....	.....	.39
30,000	.....	.....	.....	.49
30,600	.....	.....	.....	.....
31,800	.....	.....	.....	.....
32,000	.....	.....	.....	.97
31,000	.....	.....	.....	1.41
28,000	.....	.....	.....	1.52
26,800	.....	.....	.....	.....


C.I.
M.S.=125,000 #/SQ"
Y.P.=65,000 #/SQ"
LOADED THRU YIELD (70,000)
PERIOD OF REST 1 WK.
SPECIMEN NO. 28
TESTED MAY 7, 1915.
DIAM. = .6223"
GAGE LENGTH 10.00
LOAD :- THOUSAND LBS.
ELONGATION :- INCHES
0" .2 .4 .6 .8 1.0 1.2 1.4
0" .004 .008 .012 .016 .020 .024 .028 .032
0. 2. 4. 6. 8. 10. 12. 14. 16. 18. 20. 22. 24. 26. 28. 30. 32.

SPECIMEN NO. 29, GROUP C 2.

Loaded through yield (19,400 pounds).
Period of rest, one week.

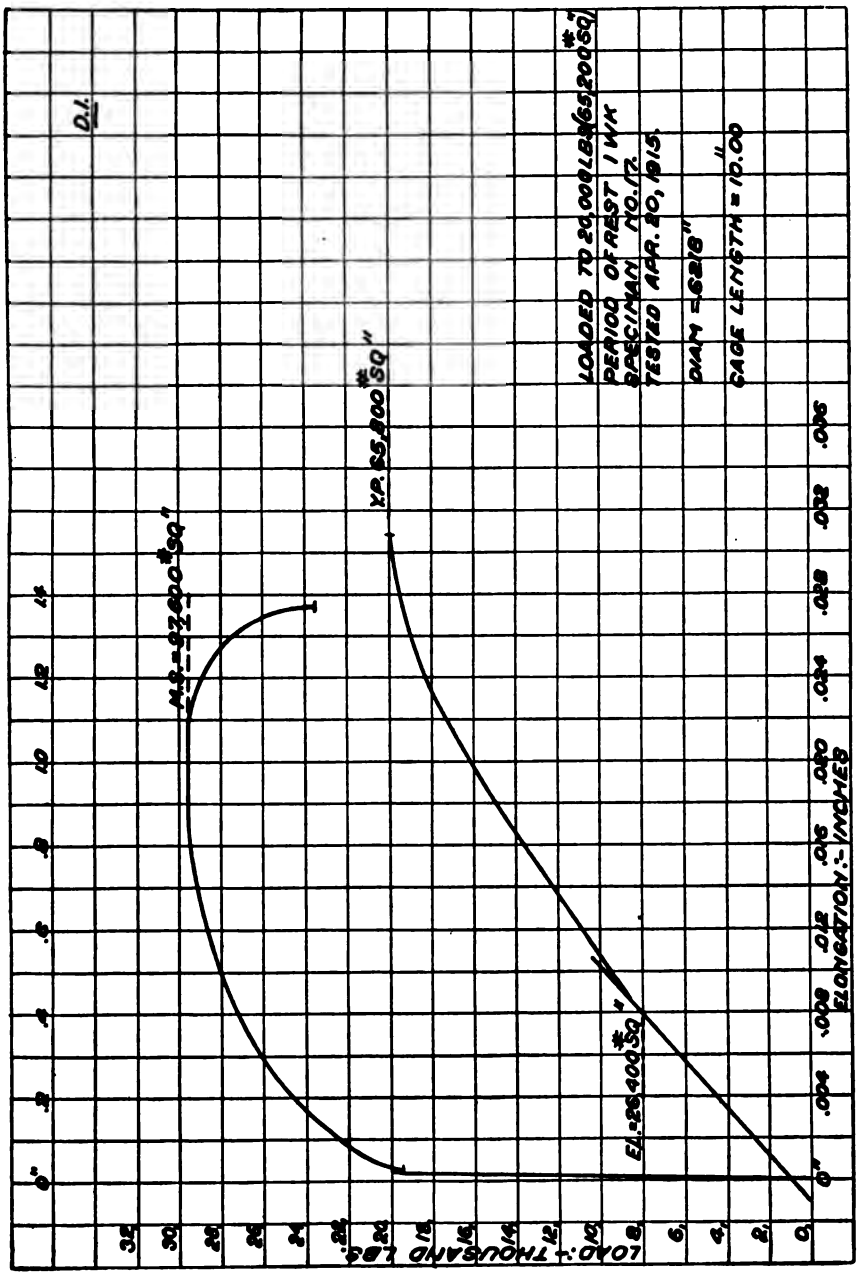
Load.	Extensometers.			
	Left.	Right.	Mean.	
			8-inch gauge.	10-inch gauge.
Pounds.	*Inch.*	*Inch.*	*Inch.*	*Inch.*
1,000	0.00000	0.00000	0.00000	0.00000
2,000	.00075	.00090	.000825	.00103
3,000	.00165	.00185	.00175	.00219
4,000	.00245	.00280	.002625	.00328
5,000	.00325	.00385	.00355	.00444
6,000	.00410	.00475	.004425	.00553
7,000	.00500	.00570	.00535	.00669
8,000	.00595	.00662	.00630	.00788
9,000	.00695	.00765	.00730	.00913
10,000	.00805	.00865	.00835	.01044
11,000	.00920	.00970	.00945	.01181
12,000	.01020	.01075	.010475	.01308
13,000	.01140	.01200	.01170	.01462
14,000	.01250	.01315	.012825	.01604
15,000	.01385	.01445	.01415	.01770
16,000	.01510	.01565	.015375	.01920
17,000	.01650	.01680	.01665	.02080
18,000	.01800	.01820	.0181	.02260
18,600	.01920	.01920	.0192	.02400
19,000	.02080	.02050	.0207	.02587
19,200	.0212	.02080	.0210	.02625
19,400	.0222	.02170	.02195	.02745
19,600	.0231	.02250	.0228	.0285
19,800	.0252	.02420	.0247	.0209
				Scale reading.
19,000	.....	.....	.....	.05
20,000	.....	.....	.....	.05
22,000	.....	.....	.....	.09
24,000	.....	.....	.....	.15
26,000	.....	.....	.....	.22
28,000	.....	.....	.....	.32
29,000	.....	.....	.....	.39
30,000	.....	.....	.....	.48
30,800	.....	.....	.....	.59
31,300	.....	.....	.....	.68
31,600	.....	.....	.....	.77
32,000	.....	.....	.....	.98
31,000	.....	.....	.....	.....
28,000	.....	.....	.....	.....
26,500	.....	.....	.....	.....


G2
M.S=106,300 #.SQ."
Yp=64800 #.SQ."
E.=27,300 #.SQ."
LOADED THRU. YIELD (no load)
PERIOD OF REST 1 W.K.
SPECIMEN NO. 28.
TESTED MAY 7, 1915.
DIAM. = .6186"
GAGE LENGTH 10.00"
LOAD THOUSAND LBS.
ELONGATION - INCHES.

SPECIMEN NO. 17, GROUP D 1.

Loaded to 20,000 pounds.
Period of rest, one week.

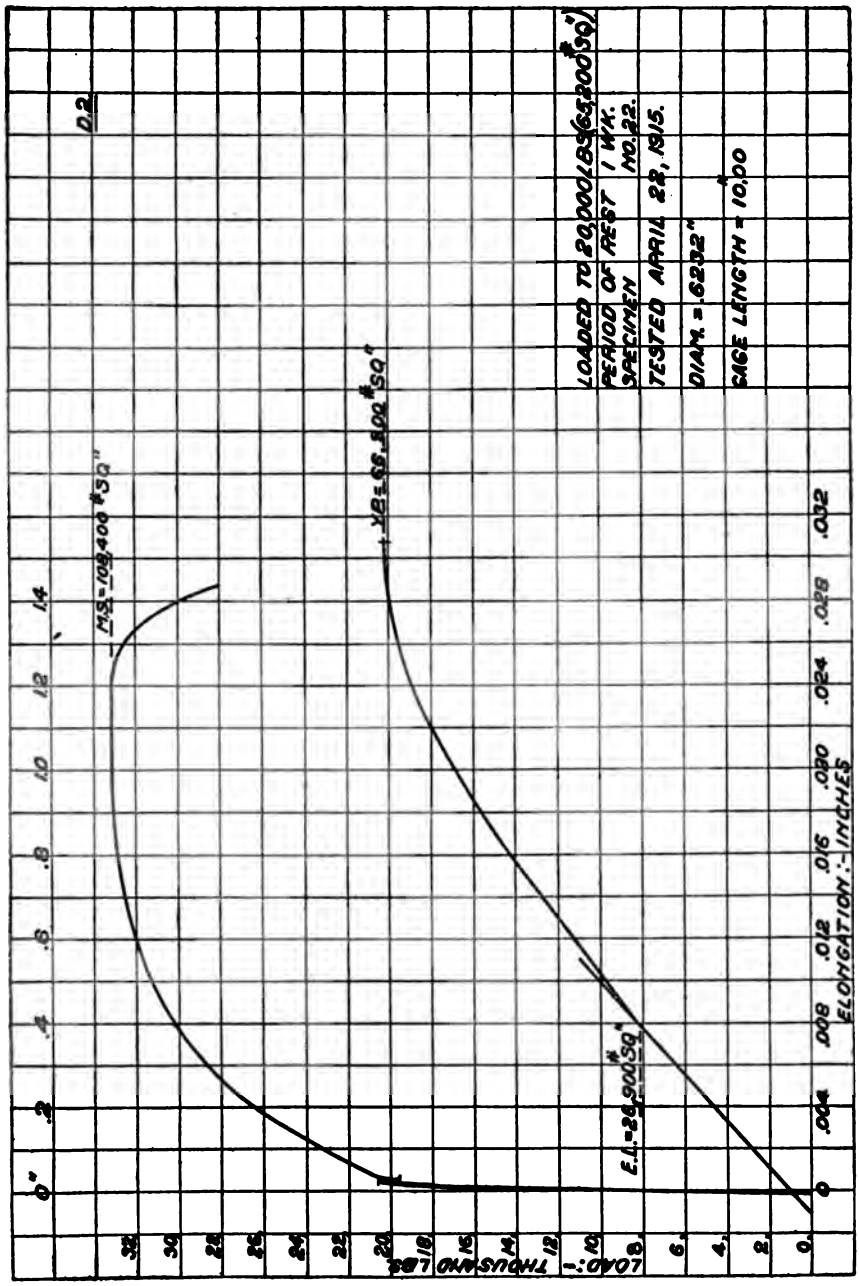
Load.	Extensometers.			
	Left.	Right.	Mean.	
			8-inch gauge.	10-inch gauge.
Pounds.	*Inch.*	*Inch.*	*Inch.*	*Inch.*
1,000	0.00000	0.00000	0.00000	0.00000
2,000	.00085	.00095	.00090	.00113
4,000	.00265	.00265	.00265	.00331
5,000	.00360	.00365	.003625	.00453
6,000	.00450	.00450	.00450	.00563
7,000	.00550	.00545	.005475	.00684
7,600	.00600	.00600	.00600	.00750
8,200	.00660	.00660	.00660	.00825
9,000	.00740	.00750	.00745	.00931
10,000	.00860	.00860	.00860	.01075
11,000	.00970	.00965	.009675	.01209
12,000	.01095	.01090	.010925	.01366
14,000	.01330	.01330	.01330	.01663
16,000	.01575	.01575	.01575	.01968
18,000	.01870	.01860	.01865	.02330
19,000	.02100	.02060	.02080	.02600
20,000	.02530	.02460	.02495	.03120
				Scale reading.
19,500	.....	.....	.....	0.03
20,000	.....	.....	.....	.04
21,000	.....	.....	.....	.05
22,000	.....	.....	.....	.09
23,000	.....	.....	.....	.13
24,000	.....	.....	.....	.17
25,000	.....	.....	.....	.23
26,000	.....	.....	.....	.29
27,000	.....	.....	.....	.38
28,000	.....	.....	.....	.49
29,000	.....	.....	.....	.66
29,600	.....	.....	.....	.98
29,000	.....	.....	.....	1.19
27,000	.....	.....	.....	1.32
23,500	.....	.....	.....	1.37


O.I.
LOADED TO 20,000 LBS. (65,200 #/SQ.")
PERIOD OF REST 1 WK
SPECIMAN NO. 12
TESTED MAR. 20, 1915.
DIAM = .6218"
CAGE LENGTH = 10.00
Y2 = 65,200 #/SQ"
Y1 = 62,400 #/SQ"
EL. = 28,400 #/SQ"
LOAD IN THOUSAND LBS.
ELONGATION IN INCHES

SPECIMEN NO. 22, GROUP D 2.

Loaded to 20,000 pounds.
Period of rest, one week.

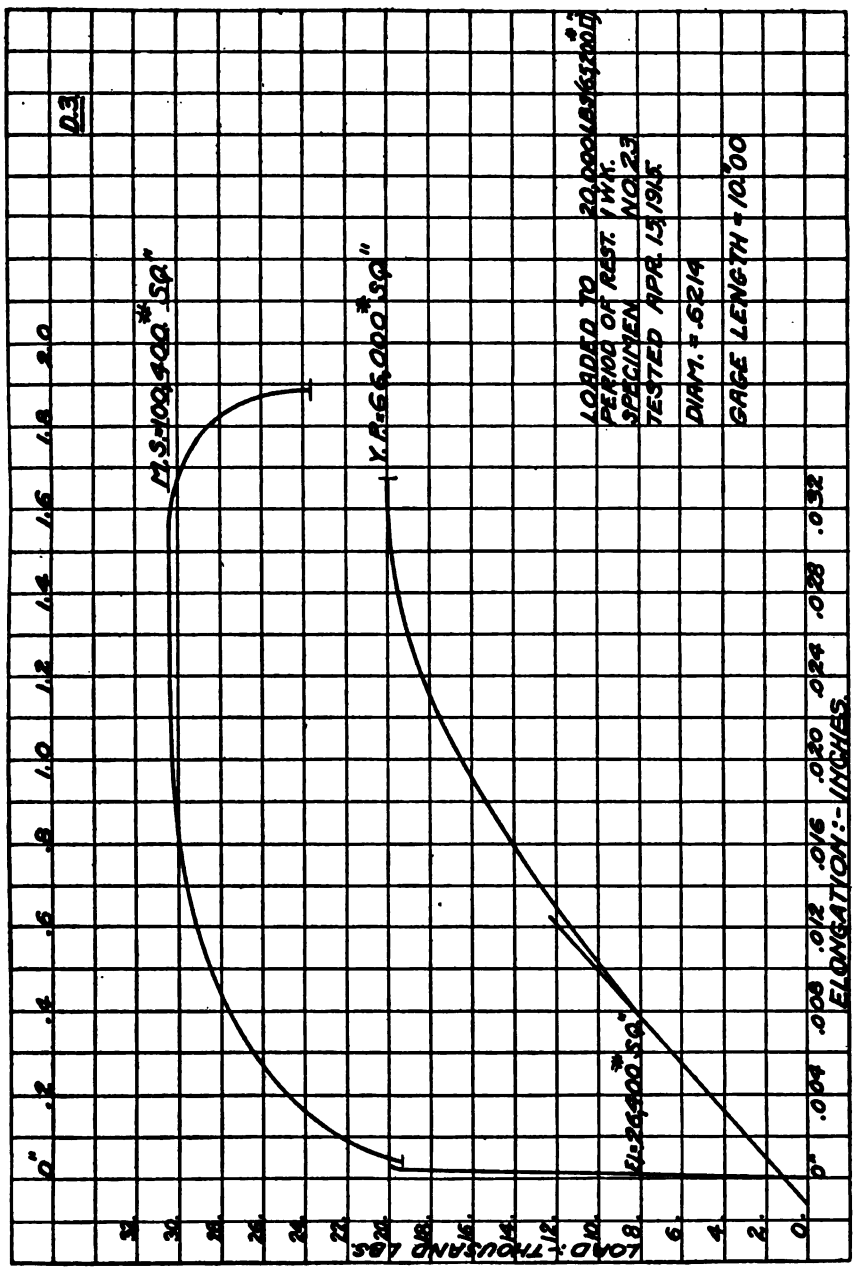
Load.	Extensometers.			
	Left.	Right.	Mean.	
			8-inch gauge.	10-inch gauge.
Pounds.	*Inch.*	*Inch.*	*Inch.*	*Inch.*
1,000	0.00000	0.00000	0.00000	0.00000
2,000	.00095	.00080	.000875	.00109
3,000	.00190	.00150	.00170	.00213
4,000	.00295	.00230	.002625	.00328
5,000	.00395	.00305	.00350	.00438
6,000	.00490	.00380	.00435	.00544
7,000	.00600	.00465	.005325	.00666
8,000	.00700	.00550	.006250	.00781
9,000	.00800	.00630	.00715	.00894
10,000	.00910	.00735	.008225	.01028
11,000	.01020	.00840	.00930	.01163
12,000	.01120	.00950	.01035	.01294
13,000	.01230	.01055	.011425	.01428
14,000	.01345	.01165	.01255	.01569
15,000	.01470	.01280	.01375	.01719
16,000	.01590	.01410	.01500	.01875
17,000	.01720	.01535	.016273	.02034
18,000	.01850	.01675	.017625	.02203
19,000	.02020	.01860	.01940	.02425
19,600	.02170	.02030	.02100	.02625
20,200	.02500	.02410	.02455	.03069
20,600	.02900	.02820	.02860	.03575
				Scale reading.
19,800	.....	.....	.....	0.03
20,600	.....	.....	.....	.04
21,000	.....	.....	.....	.....
24,000	.....	.....	.....	.07
23,000	.....	.....	.....	.10
24,000	.....	.....	.....	.13
25,000	.....	.....	.....	.16
26,000	.....	.....	.....	.18
27,000	.....	.....	.....	.23
28,000	.....	.....	.....	.27
29,000	.....	.....	.....	.33
30,000	.....	.....	.....	.39
20,500	.....	.....	.....	.43
31,000	.....	.....	.....	.48
31,500	.....	.....	.....	.53
32,000	.....	.....	.....	.61
32,500	.....	.....	.....	.70
33,000	.....	.....	.....	.89
33,100	.....	.....	.....	1.05
32,000	.....	.....	.....	1.33
31,000	.....	.....	.....	1.37
29,000	.....	.....	.....	1.42
28,000	.....	.....	.....	.....


LOADED TO 20,000 LBS (65,200 #/SQ")
PERIOD OF REST 1 WK.
SPECIMEN NO. 22.
TESTED APRIL 22, 1915.
DIAM. = .6252"
GAGE LENGTH = 10.00"
E.L. = 39,900 #/SQ"
ELONGATION :- INCHES
LOAD :- THOUSAND LBS.

SPECIMEN NO. 23, GROUP D 3.

Loaded to 20,000 pounds.
Period of rest, one week.

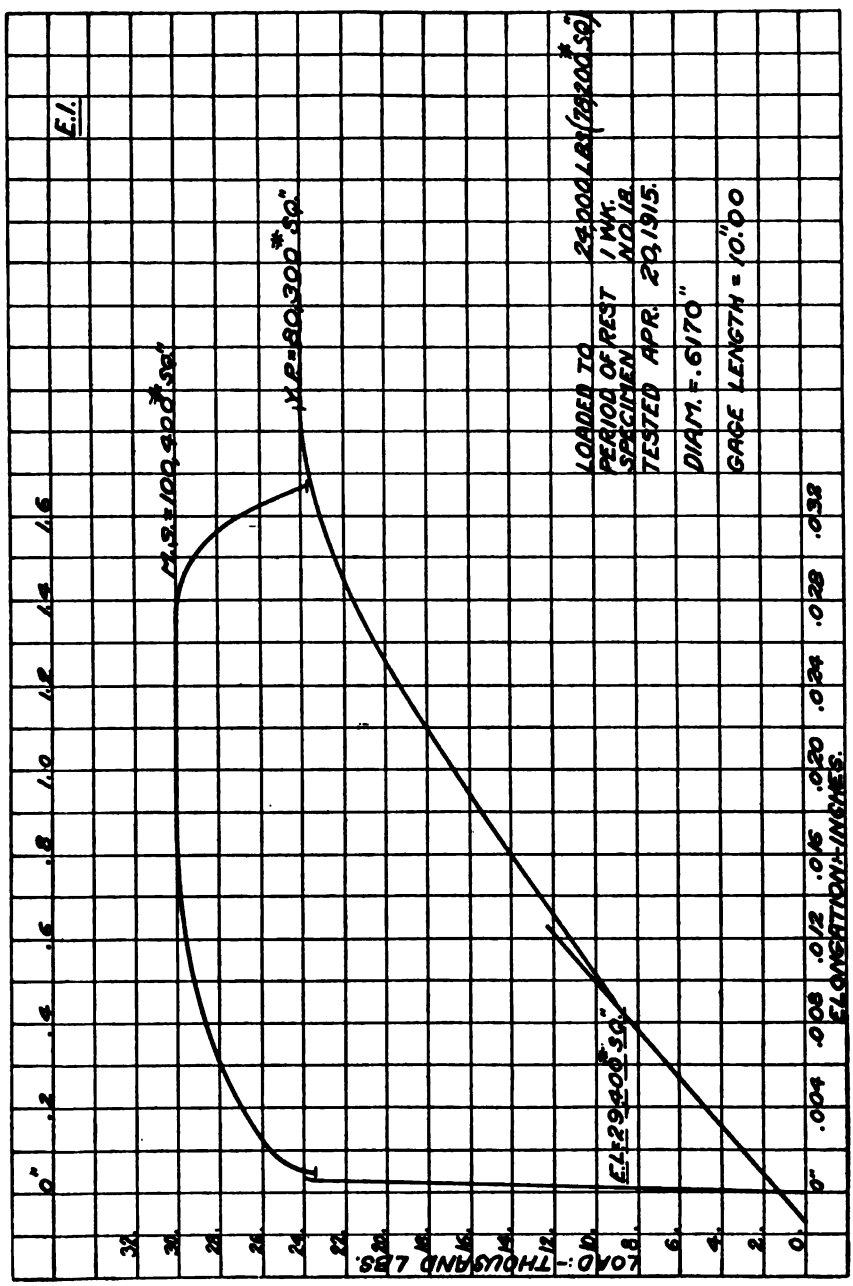
Load.	Extensometers.			
	Left.	Right.	Mean.	
			8-inch gauge.	10-inch gauge.
Pounds.	*Inch.*	*Inch.*	*Inch.*	*Inch.*
1,000	0.00000	0.00000	0.00000	0.00000
2,000	.00080	.00080	.00080	.00100
3,000	.00160	.00175	.001675	.00209
4,000	.00240	.00275	.002575	.00322
5,000	.00320	.00385	.003525	.00441
6,000	.00390	.00480	.004350	.00544
7,000	.00470	.00585	.005275	.00659
8,000	.00555	.00690	.006225	.00778
9,000	.00645	.00800	.007225	.00903
10,000	.00745	.00910	.008275	.01034
11,000	.00850	.01020	.00935	.01169
12,000	.00965	.01135	.01050	.01313
13,000	.01075	.01255	.01165	.01456
14,000	.01200	.01380	.01290	.01613
15,000	.01330	.01500	.01415	.01769
16,000	.01460	.01620	.01540	.01925
17,000	.01610	.01760	.01685	.02106
17,600	.01700	.01850	.01775	.02219
18,200	.01810	.01950	.01880	.02350
18,800	.01940	.02070	.02005	.02506
19,400	.02130	.02240	.02185	.02731
20,000	.02620	.02700	.02660	.03325
20,000	.02780	.02860	.02820	.03525
				Scale reading.
19,500	.....	.....	.....	.04
21,500	.....	.....	.....	.06
22,000	.....	.....	.....	.09
23,000	.....	.....	.....	.13
24,000	.....	.....	.....	.17
25,000	.....	.....	.....	.22
26,000	.....	.....	.....	.27
27,000	.....	.....	.....	.35
28,000	.....	.....	.....	.44
28,500	.....	.....	.....	.50
29,000	.....	.....	.....	.57
29,500	.....	.....	.....	.67
30,000	.....	.....	.....	.83
30,200	.....	.....	.....	.95
30,300	.....	.....	.....	1.03
30,400	.....	.....	.....	1.17
30,000	.....	.....	.....	1.66
29,000	.....	.....	.....	1.77
28,000	.....	.....	.....	1.83
26,000	.....	.....	.....	1.87
23,600	.....	.....	.....	.....


23
M.S.=104,400 #/SQ"
Y.P.=66,000 #/SQ"
E=24,400 #/SQ"
LOADED TO 20,000 LBS. 1 HR.
PERIOD OF REST.
SPECIMEN NO. 23
TESTED APR. 15, 1915
DIAM. = .6214
GAGE LENGTH = 10.00
LOAD ÷ THOUSAND LBS.
ELONGATION:- INCHES.

SPECIMEN NO. 18, GROUP E 1.

Loaded to 24,000 pounds.
Period of rest, one week.

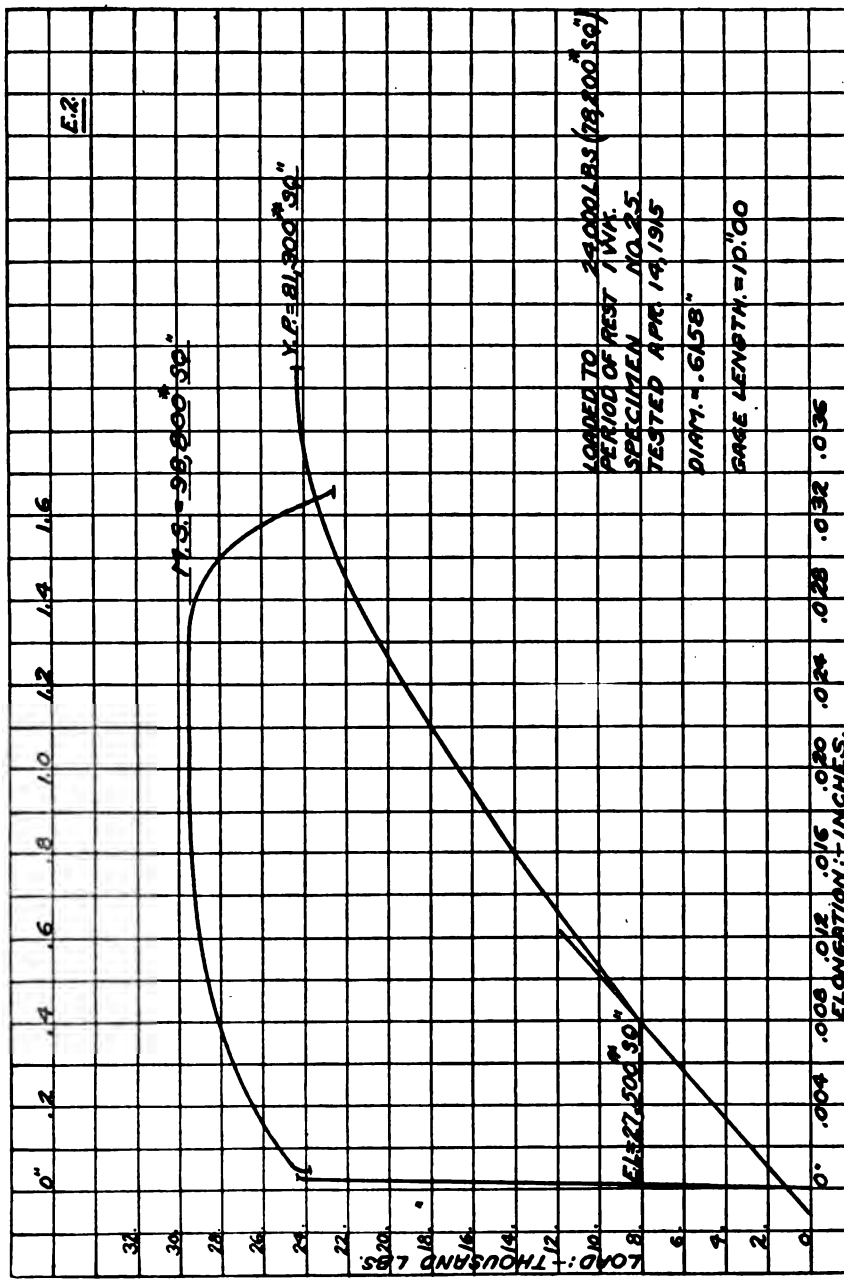
Load.	Extensometers.			
	Left.	Right.	Mean.	
			8-inch gauge.	10-inch gauge.
Pounds.	*Inch.*	*Inch.*	*Inch.*	*Inch.*
1,000	0.00000	0.00000	0.00000	0.00000
2,000	.00090	.00070	.00080	.00100
3,000	.00190	.00155	.001725	.00216
4,000	.00290	.00250	.00270	.00338
5,000	.00375	.00330	.003525	.00441
6,000	.00465	.00410	.004375	.00547
7,000	.00570	.00510	.00540	.00675
7,600	.00620	.00560	.00590	.00738
8,200	.00680	.00625	.006525	.00816
9,000	.00750	.00700	.00725	.00906
10,000	.00850	.00800	.00815	.01031
11,000	.00970	.00910	.00940	.01175
12,000	.01085	.01030	.010575	.01323
13,000	.01190	.01135	.011625	.01454
14,000	.01310	.01250	.01280	.01600
16,000	.01550	.01500	.01525	.01907
18,000	.01795	.01750	.017725	.02218
20,000	.02070	.02020	.02045	.02555
22,000	.02410	.02360	.02385	.0298
23,000	.02600	.02560	.02580	.03226
24,000	.03000	.02950	.02975	.0372
				Scale reading.
23,500	.....	.....	.....	.04
24,000	.....	.....	.....	.045
25,000	.....	.....	.....	.06
26,000	.....	.....	.....	.14
27,000	.....	.....	.....	.20
28,000	.....	.....	.....	.31
29,000	.....	.....	.....	.47
29,500	.....	.....	.....	.61
30,000	.....	.....	.....	1.03
30,000	.....	.....	.....	1.35
29,000	.....	.....	.....	1.53
27,000	.....	.....	.....	1.61
23,500	.....	.....	.....	1.68


E.I.
LOAD IN THOUSAND LBS.
ELONGATION IN INCHES.
0" .2 .4 .6 .8 1.0 1.2 1.4 1.6
0 2 4 6 8 10 12 14 16 18 20 22 24 26 28 30 32
0" .004 .008 .012 .016 .020 .024 .028 .032
E.I. 29400 #/SQ.
μ.L.P.=80,300 #/SQ.
P.L.=102,900 #/SQ.
LOADED TO 25,000 LBS (79200 #/SQ.)
PERIOD OF REST 1 HR.
SPECIMEN NO 18.
TESTED APR. 29, 1915.
DIAM. = .6170"
GAGE LENGTH = 10.00

SPECIMEN NO. 25, GROUP E 2.

Loaded to 24,000 pounds.
Period of rest, one week.

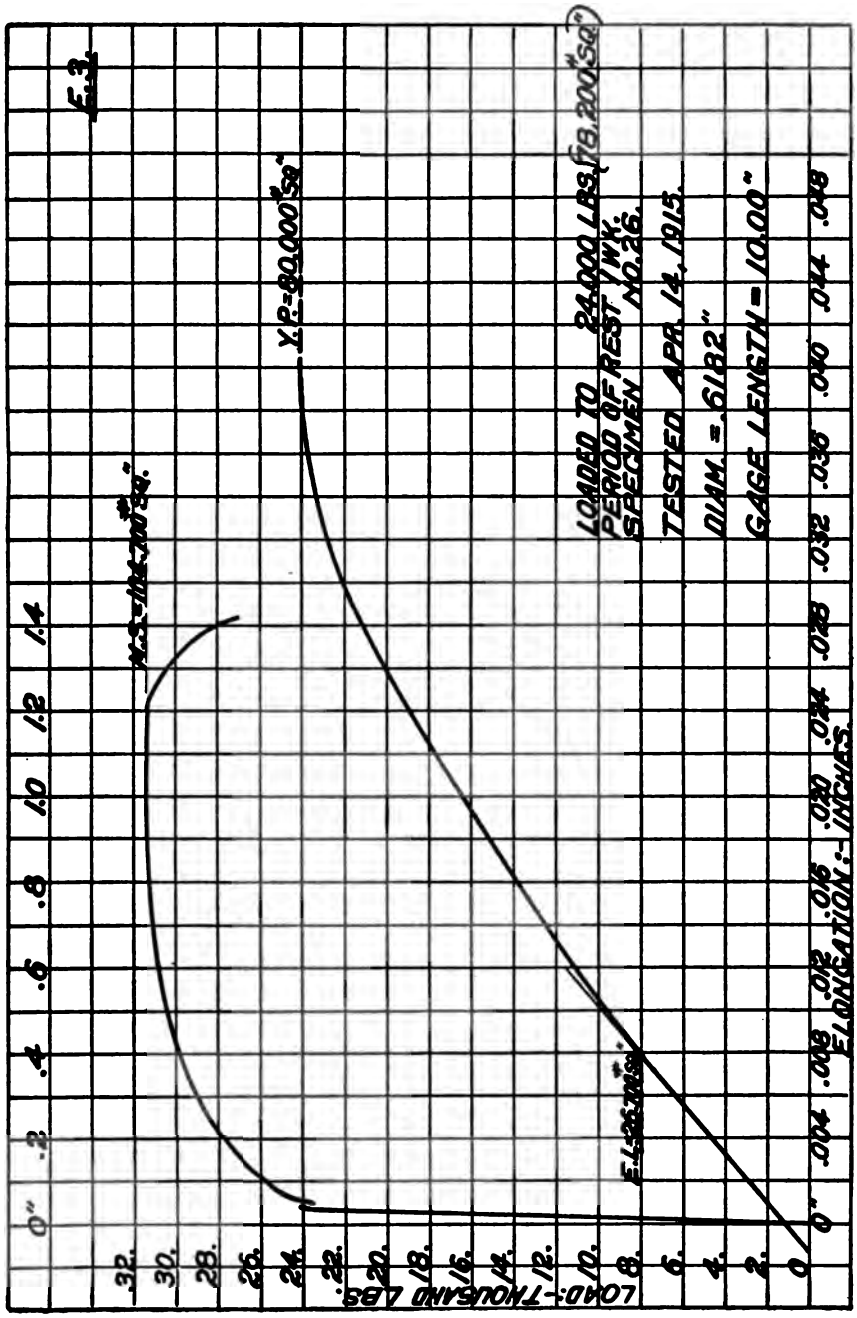
Load.	Extensometers.			
	Left.	Right.	Mean.	
			8-inch gauge.	10-inch gauge.
Pounds.	*Inch.*	*Inch.*	*Inch.*	*Inch.*
1,000	0.00000	0.00000	0.00000	0.00000
2,000	.00090	.00085	.00088	.00110
3,000	.00180	.00175	.00178	.00222
4,000	.00275	.00260	.00268	.00335
5,000	.00370	.00355	.00363	.00453
6,000	.00460	.00455	.00458	.00572
7,000	.00555	.00550	.00553	.00690
8,000	.00640	.00645	.00643	.00803
9,000	.00735	.00745	.00740	.00925
10,000	.00830	.00845	.00838	.01047
11,000	.00935	.00955	.00945	.01181
12,000	.01050	.01060	.01055	.01319
13,000	.01155	.01165	.01160	.01450
14,000	.01270	01290	.01280	.01600
15,000	.01400	.01410	.01405	.01756
16,000	.01520	.01550	.01535	.01919
17,000	.01630	.01670	.01650	.02063
18,000	.01760	.01800	.01780	.02225
19,000	.01900	.01940	.01920	.02400
20,000	.02050	.02090	.02070	.02588
21,000	.02220	.02250	.02235	.02794
22,000	.02370	.02420	.02395	.02994
23,000	.02570	.02640	.02605	.03256
23,400	.02740	.02800	.02770	.03463
23,800	.02850	.02960	.02905	.03631
24,200	.0300	.0300	.0300	.0375
				Scale reading.
23,600	.....	.....	.....	.05
24,200	.....	.....	.....	.05
25,000	.....	.....	.....	.....
26,000	.....	.....	.....	.15
27,000	.....	.....	.....	.25
28,000	.....	.....	.....	.38
28,500	.....	.....	.....	.47
29,000	.....	.....	.....	.64
29,300	.....	.....	.....	.80
29,400	.....	.....	.....	1.06
29,000	.....	.....	.....	1.40
28,000	.....	.....	.....	1.50
27,000	.....	.....	.....	1.55
25,000	.....	.....	.....	1.61
22,500	.....	.....	.....	1.66


E.2
U.T.S. = 36,800 # 30"
Y.P. = 31,300 # 30"
LOADED TO 24,000 LBS (78,400 #/sq")
PERIOD OF REST 1 WK.
SPECIMEN NO. 25
TESTED APR. 14, 1915
DIAM. = .6158"
GAGE LENGTH = 10".00
E.L. = 27,200 # 30"
LOAD :- THOUSAND LBS.
ELONGATION :- INCHES.
0" .2 .4 .6 .8 1.0 1.2 1.4 1.6
0. .004 .008 .012 .016 .020 .024 .028 .032 .036
0. 2. 4. 6. 8. 10. 12. 14. 16. 18. 20. 22. 24. 26. 28. 30. 32.

SPECIMEN NO. 26, GROUP E 3.

Loaded to 24,000 pounds.
Period of rest, one week.

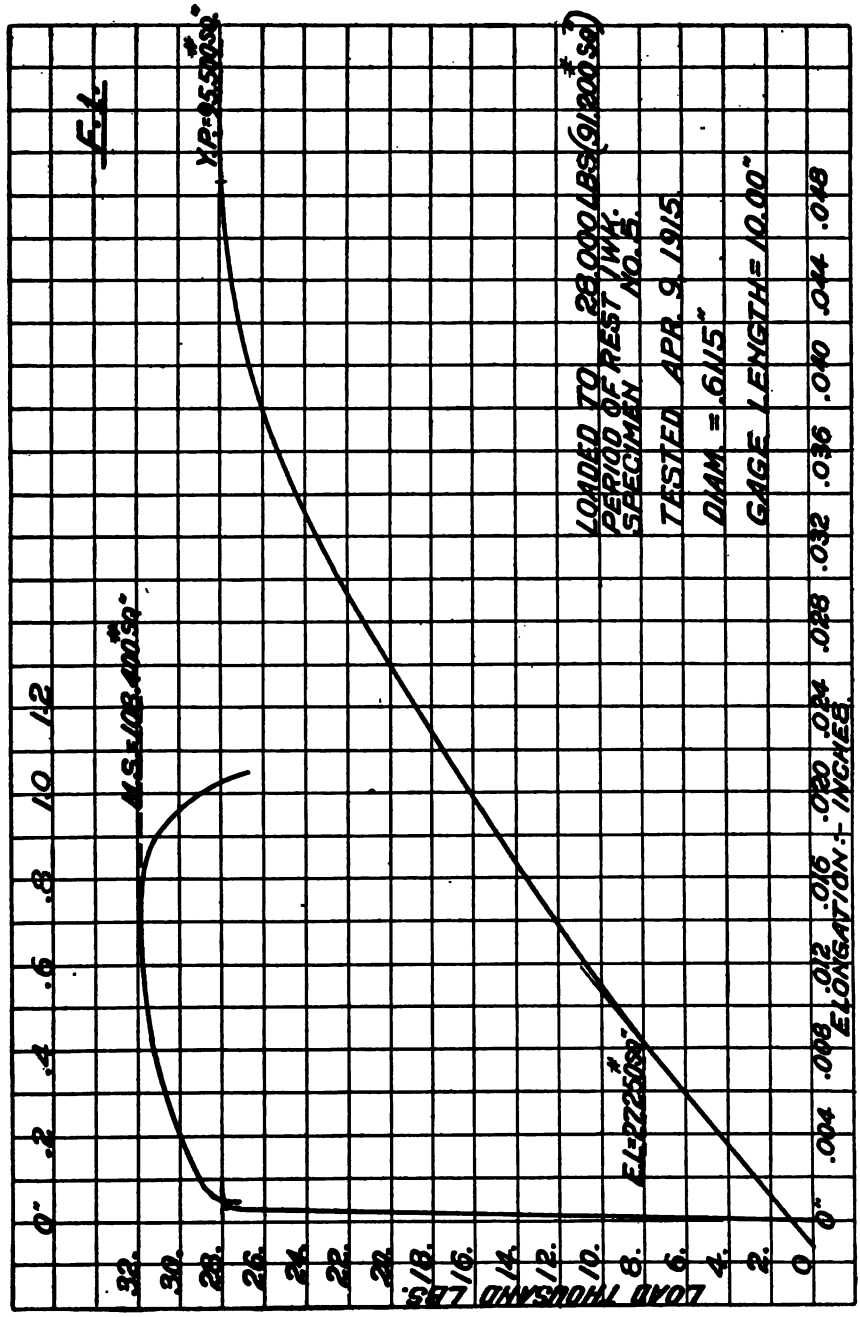
Load.	Extensometers.			
	Left.	Right.	Mean.	
			8-inch gauge.	10-inch gauge.
Pounds.	*Inch.*	*Inch.*	*Inch.*	*Inch.*
1,000	0.00000	0.00000	0.00000	0.00000
2,000	.00080	.00065	.00073	.00091
3,000	.00180	.00155	.00168	.00210
4,000	.00280	.00240	.00260	.00325
5,000	.00380	.00330	.00355	.00444
6,000	.00475	.00425	.00450	.00562
7,000	.00560	.00505	.00533	.00666
8,000	.00660	.00600	.00630	.00787
9,000	.00760	.00715	.00738	.00922
10,000	.00855	.00815	.00835	.01044
11,000	.00965	.00930	.00948	.01183
12,000	.01075	.01035	.01055	.01319
13,000	.01195	.01155	.01175	.01469
14,000	.01315	.01280	.01298	.01622
15,000	.01430	.01405	.01418	.01772
16,000	.01565	.01530	.01548	.01934
17,000	.01680	.01650	.01673	.02091
18,000	.01810	.01785	.01798	.02247
19,000	.01930	.01910	.01920	.02400
20,000	.02070	.02050	.02060	.02575
21,000	.02230	.02200	.02215	.02769
22,000	.02400	.02370	.02385	.02981
23,000	.02620	.02600	.02610	.03263
23,400	.02750	.02730	.02740	.03425
23,800	.02920	.02910	.02915	.03644
24,000	.03120	.03120	.03120	.03900
24,000	.03200	.03210	.03205	.04006
				Scale reading.
23,500				.05
24,000				
25,000				.07
26,000				.12
27,000				.16
28,000				.22
29,000				.30
29,500				.35
30,000				.44
30,600				.57
31,000				.65
31,300				.82
31,400				.92
31,430				1.03
31,000				1.25
30,000				1.32
				1.37
28,000				1.40
27,000				1.42
26,000				1.45
24,980				


E.3.
Y.P.=80,000 lbs. per sq. in.
LOADED TO 24,000 LBS. (78,200 lbs. per sq. in.)
PERIOD OF REST 1 WK.
SPECIMEN NO. 26.
TESTED APR. 14, 1915.
DIAM. = .6182"
GAGE LENGTH = 10.00"
LOAD:-THOUSAND LBS.
ELONGATION:-INCHES.

SPECIMEN NO. 5, GROUP F 1.

Loaded to 28,000 pounds.
Period of rest, one week.

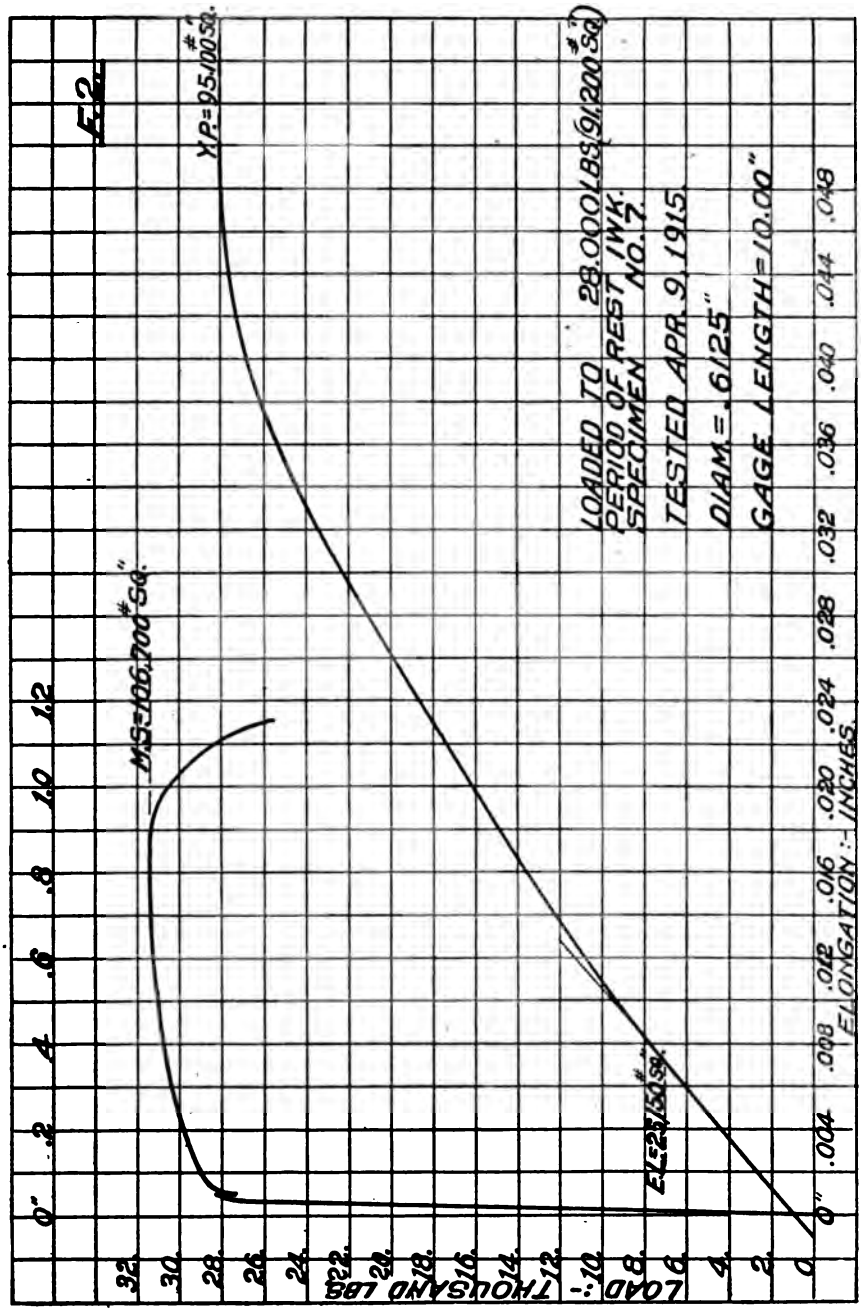
Load.	Extensometers.			
	Left.	Right.	Mean.	
			8-inch gauge.	10-inch gauge.
Pounds.	*Inch.*	*Inch.*	*Inch.*	*Inches.*
1,000	0.00000	0.00000	0.00000	0.00000
2,000	.00095	.00100	.00098	.00123
4,000	.00280	.00270	.00285	.00356
6,000	.00470	.00470	.00470	.00588
8,000	.00670	.00660	.00665	.00832
10,000	.00885	.00880	.00883	.01103
12,000	.01095	.01100	.01098	.01372
14,000	.01330	.01325	.01328	.01660
16,000	.01580	.01575	.01578	.01972
16,400	.01620	.01615	.01618	.02028
16,800	.01680	.01670	.01675	.02094
17,000	.01710	.01705	.01708	.02135
17,200	.01730	.01720	.01725	.02156
17,600	.01770	.01765	.01768	.02210
18,000	.01820	.01815	.01818	.02272
18,400	.01875	.01870	.01873	.02341
18,800	.01920	.01915	.01918	.02397
19,200	.01970	.01970	.01970	.02463
19,600	.02030	.02030	.02030	.02538
20,000	.02080	.02080	.02080	.02600
20,400	.02130	.02130	.02130	.02663
20,800	.02190	.02180	.02185	.02731
21,200	.02240	.02235	.02238	.02797
21,600	.02290	.02290	.02290	.02863
22,000	.02345	.02340	.02343	.02929
22,400	.02400	.02400	.02400	.03000
22,800	.02460	.02470	.02465	.03081
23,200	.02520	.02515	.02518	.03147
23,600	.02580	.02570	.02575	.03219
24,000	.02650	.02640	.02645	.03306
24,400	.02720	.02710	.02715	.03394
24,800	.02790	.02780	.02785	.03481
25,200	.02870	.02860	.02865	.03581
25,600	.02945	.02940	.02943	.03678
26,000	.03030	.03020	.03025	.03781
26,400	.03100	.031	.03100	.03875
26,800	.03200	.03200	.03200	.04000
27,200	.03340	.03330	.03335	.04169
27,600	.03510	.03500	.03505	.04381
28,000	.03900	.03900	.03900	.04875
				Scale reading.
27,400	.....	.....	.....	0.05
28,000	.....	.....	.....	.06
29,000	.....	.....	.....	.09
30,000	.....	.....	.....	.20
31,000	.....	.....	.....	.35
31,800	.....	.....	.....	.....
31,000	.....	.....	.....	.91
29,000	.....	.....	.....	1.00
28,000	.....	.....	.....	1.03
26,000	.....	.....	.....	.....


E1
YP=55000#
MS=102,400#
LOADED TO 28,000 LBS (91200 #²)
PERIOD OF REST 1 WK.
SPECIMEN NO. 5.
TESTED APR. 9, 1915.
DIAM. = .615"
GAGE LENGTH = 10.00"
EL=27225#
LOAD THOUSAND LBS.
ELONGATION:- INCHES
0 2 4 6 8 10 12
0" .004 .008 .012 .016 .020 .024 .028 .032 .036 .040 .044 .048
0 2. 4. 6. 8. 10. 12. 14. 16. 18. 20. 22. 24. 26. 28. 30. 32.

SPECIMEN NO. 7, GROUP F 2.

Loaded to 28,000 pounds.
Period of rest, one week.

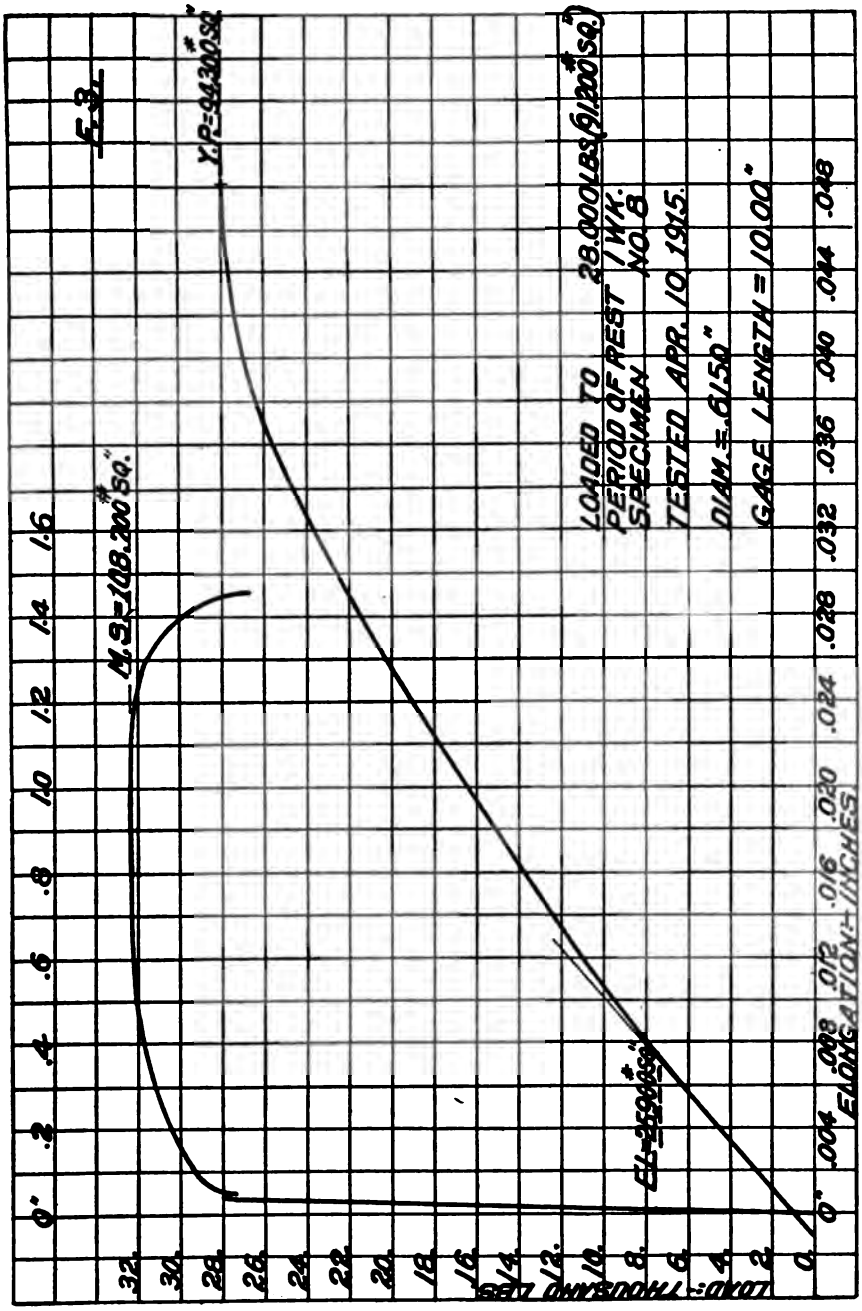
Load.	Extensometers.			
	Left.	Right.	Mean.	
			8-inch gauge.	10-inch gauge.
Pounds.	*Inch.*	*Inch.*	*Inch.*	*Inches.*
1,000	0.00000	0.00000	0.00000	0.00000
3,000	.00190	.00180	.00185	.00231
4,000	.00280	.00280	.00280	.00350
6,000	.00475	.00475	.00475	.00594
8,000	.00680	.00680	.00680	.00850
10,000	.00860	.00815	.00868	.01085
12,000	.01090	.01100	.01095	.01369
14,000	.01330	.01345	.01338	.01672
16,000	.01580	.01600	.01590	.01988
18,000	.01820	.01850	.01835	.02294
19,000	.01945	.01980	.01963	.02453
20,000	.02070	.02110	.02090	.02613
21,000	.02210	.02250	.02230	.02788
22,000	.02350	.02390	.02370	.02963
23,000	.02500	.....	.....	.03125
24,000	.02650	.....	.....	.03313
25,000	.02810	.....	.....	.03513
25,400	.02875	.....	.....	.03593
25,800	.02940	.....	.....	.03675
26,200	.03040	.....	.....	.03800
26,600	.03170	.....	.....	.03963
27,000	.03270	.....	.....	.04088
27,400	.03390	.....	.....	.04238
27,800	.03500	.....	.....	.04480
28,000	.03800	.....	.....	.04750
				Scale reading.
27,350	.....	.....	.....	0.05
28,000	.....	.....	.....	.06
29,000	.....	.....	.....	.10
30,000	.....	.....	.....	.23
30,500	.....	.....	.....	.33
31,000	.....	.....	.....	.44
31,400	.....	.....	.....	.....
31,000	.....	.....	.....	.97
29,000	.....	.....	.....	1.08
27,000	.....	.....	.....	1.14
25,300	.....	.....	.....	.....


E12
YP=95,100 Sq.
MS=106,700 Sq.
LOADED TO 29,000 LBS (91,200 Sq.)
PERIOD OF REST 1 WK.
SPECIMEN NO. 7.
TESTED APR. 9, 1915.
DIAM. = .6125"
GAGE LENGTH=10.00"
EL=25,150 Sq.
LOAD :- THOUSAND LBS.
ELONGATION :- INCHES.

SPECIMEN NO. 8, GROUP F 3.

Loaded to 28,000 pounds.
Period of rest, one week.

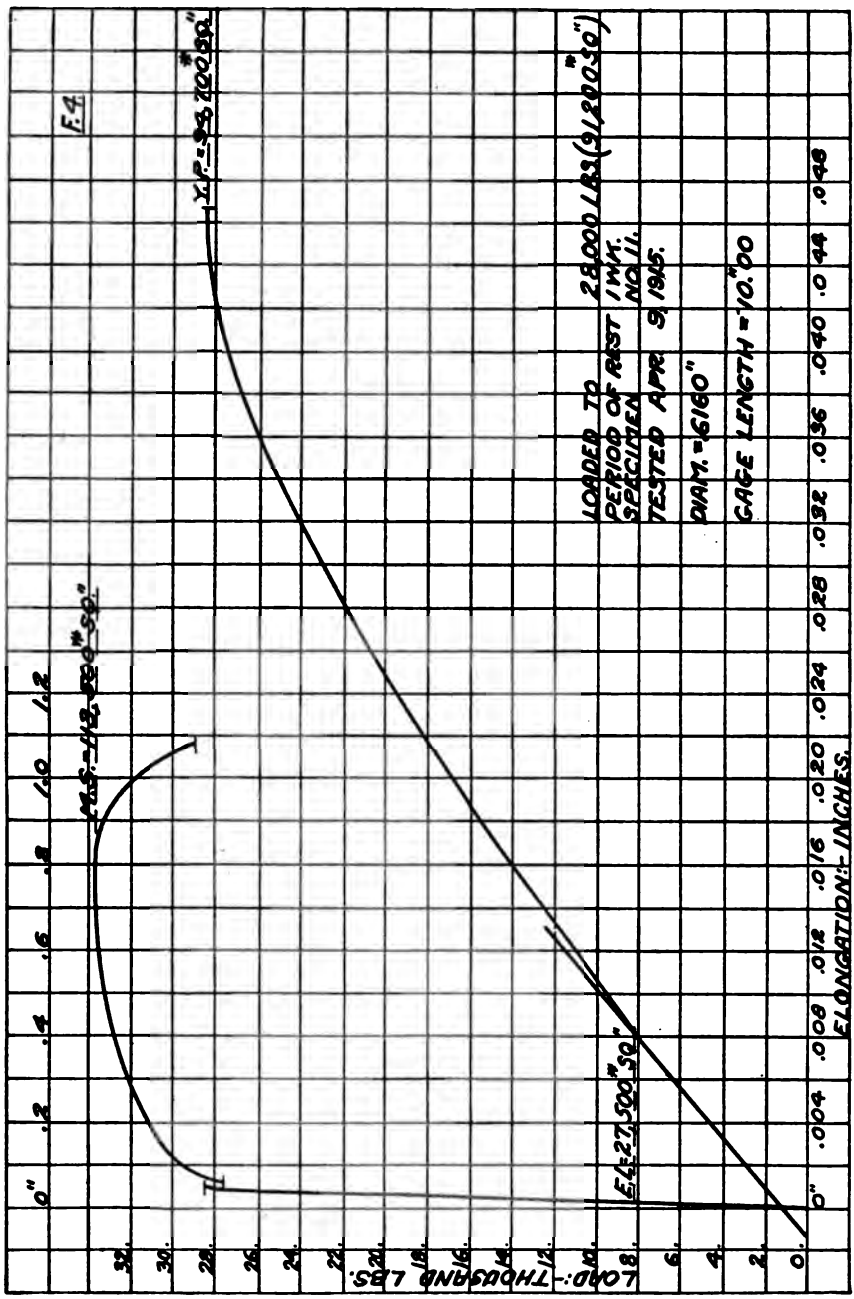
Load.	Extensometers.			
	Left.	Right.	Mean.	
			8-inch gauge.	10-inch gauge.
Pounds.	*Inch.*	*Inch.*	*Inch.*	*Inches.*
1,000	0.00000	0.00000	0.00000	0.00000
2,000	.00090	.00085	.00088	.00110
3,000	.00180	.00185	.00183	.00229
4,000	.00273	.00270	.00270	.00338
5,000	.00355	.00360	.00358	.00447
6,000	.00445	.00460	.00453	.00566
7,000	.00550	.00550	.00550	.00688
7,600	.00600	.00605	.00603	.00753
8,000	.00640	.00645	.00643	.00803
8,400	.00680	.00685	.00683	.00853
8,800	.00720	.00730	.00725	.00906
9,400	.00785	.00790	.00788	.00985
10,000	.00840	.00855	.00848	.01060
11,000	.00955	.00955	.00955	.01194
12,000	.01065	.01065	.01065	.01331
14,000	.01295	.01305	.01300	.01625
16,000	.01545	.01550	.01548	.01935
18,000	.01790	.01790	.01790	.02238
20,000	.02040	.02035	.02038	.02547
22,000	.02310	.02300	.02305	.02881
24,000	.02620	.02600	.02610	.03262
26,000	.02975	.02950	.02968	.03703
26,600	.03120	.03085	.03103	.03878
27,200	.03290	.03250	.03270	.04088
27,800	.03610	.03530	.03570	.04463
28,000	.03900	.03800	.03850	.04813
				Scale reading.
27,400	.....	.....	.....	0.05
28,000	.....	.....	.....	.....
28,500	.....	.....	.....	.....
29,000	.....	.....	.....	.08
30,000	.....	.....	.....	.16
31,000	.....	.....	.....	.28
31,600	.....	.....	.....	.37
32,000	.....	.....	.....	.51
32,260	.....	.....	.....	.66
32,300	.....	.....	.....	.....
32,200	.....	.....	.....	.....
32,000	.....	.....	.....	1.22
30,000	.....	.....	.....	1.40
28,000	.....	.....	.....	1.45
26,500	.....	.....	.....	.....


E-3
Y.P=94300 #/sq.
M.S=108,200 #/sq.
LOADED TO 38,000 LBS (91,200 #/sq.)
PERIOD OF REST 1 WK.
SPECIMEN NO. 8
TESTED APR. 10 1915.
DIAM. = .6150"
GAGE LENGTH = 10.00"
LOAD IN THOUSAND LBS
ELONGATION IN INCHES

SPECIMEN NO. 11, GROUP F 4.

Loaded to 28,000 pounds.
Period of rest, one week.

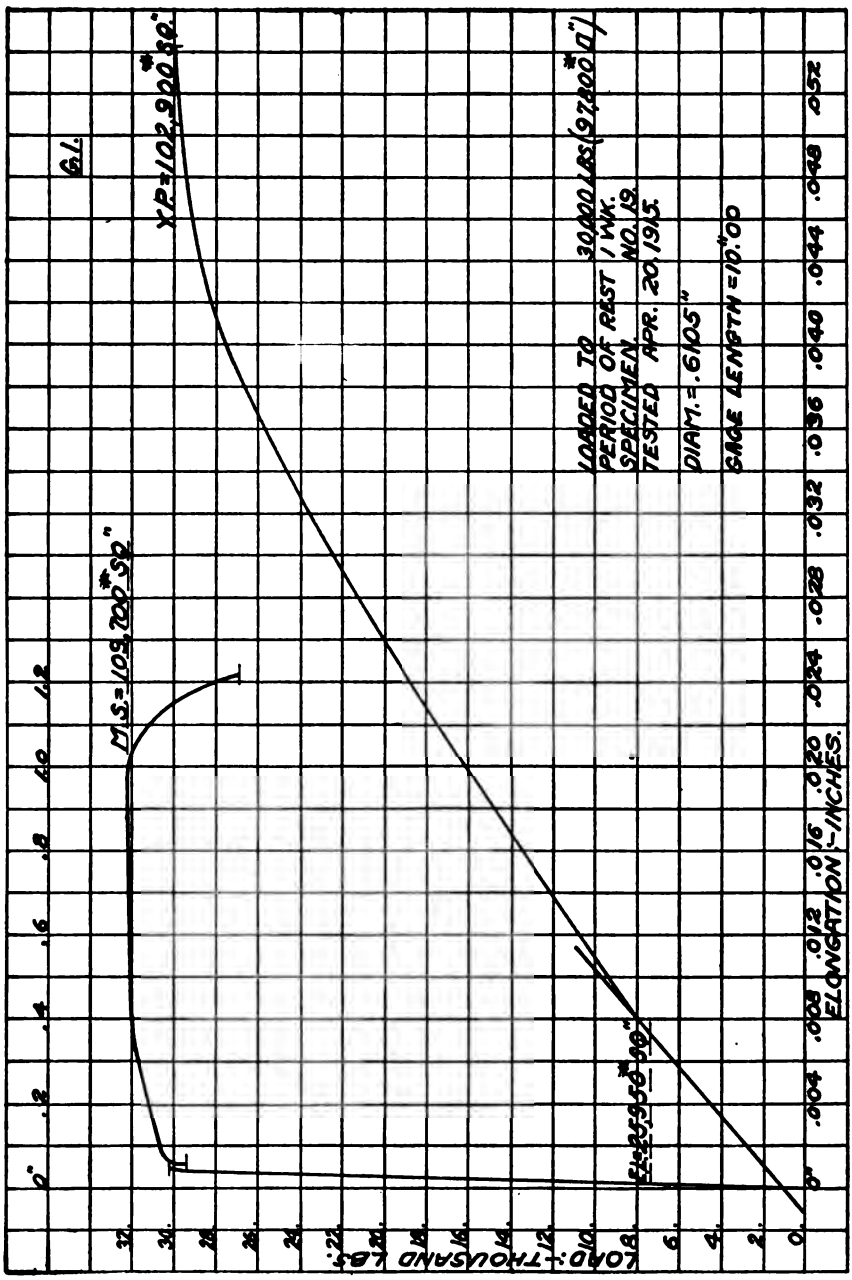
Load.	Extensometers.			
	Left.	Right.	Mean.	
			8-inch gauge.	10-inch gauge.
Pounds.	*Inch.*	*Inch.*	*Inch.*	*Inches.*
1,000	0.00000	0.00000	0.00000	0.00000
2,000	.00070	.00070	.00070	.00088
4,000	.00260	.00250	.00255	.00319
6,000	.00460	.00420	.00440	.00550
8,000	.00660	.00600	.00630	.00738
10,000	.00860	.00800	.00830	.01038
12,000	.01035	.01020	.01053	.01316
14,000	.01310	.01240	.01275	.01594
16,000	.01545	.01480	.01513	.01891
18,000	.01790	.01730	.01760	.02200
20,000	.02035	.01980	.02008	.02510
22,000	.02300	.02230	.02265	.02831
24,000	.02610	.02530	.02570	.03213
25,000	.02775	.02685	.02730	.03413
26,000	.02950	.02855	.02903	.03629
26,400	.03040	.02940	.02990	.03738
26,800	.03130	.03040	.03085	.03856
27,200	.03220	.03130	.03175	.03969
27,600	.03320	.03280	.03300	.04125
28,000	.03600	.03500	.03550	.04438
28,200	.03720	.....	.03720	.04650
				Scale reading.
27,500	.....	.....	.....	0.05
28,000	.....	.....	.....	.05
28,500	.....	.....	.....	.....
29,000	.....	.....	.....	.....
29,500	.....	.....	.....	.10
31,000	.....	.....	.....	.21
32,000	.....	.....	.....	.27
33,000	.....	.....	.....	.43
33,500	.....	.....	.....	.57
33,800	.....	.....	.....	.....
32,000	.....	.....	.....	1.00
31,000	.....	.....	.....	1.04
29,000	.....	.....	.....	.....


E-4
LOAD:- THOUSAND LBS.
ELONGATION:- INCHES.
LOADED TO 28,000 LBS (91200 #/SQ.")
PERIOD OF REST 1 WK.
SPECIMEN NO 11.
TESTED APR. 9 1915.
DIAM. = .6160"
GAGE LENGTH = 10.00"
E = 27,500 #/SQ."
XP = 33,100 #/SQ."
MS = 42,500 #/SQ."

SPECIMEN NO. 19, GROUP G 1.

Loaded to 30,000 pounds.
Period of rest, one week.

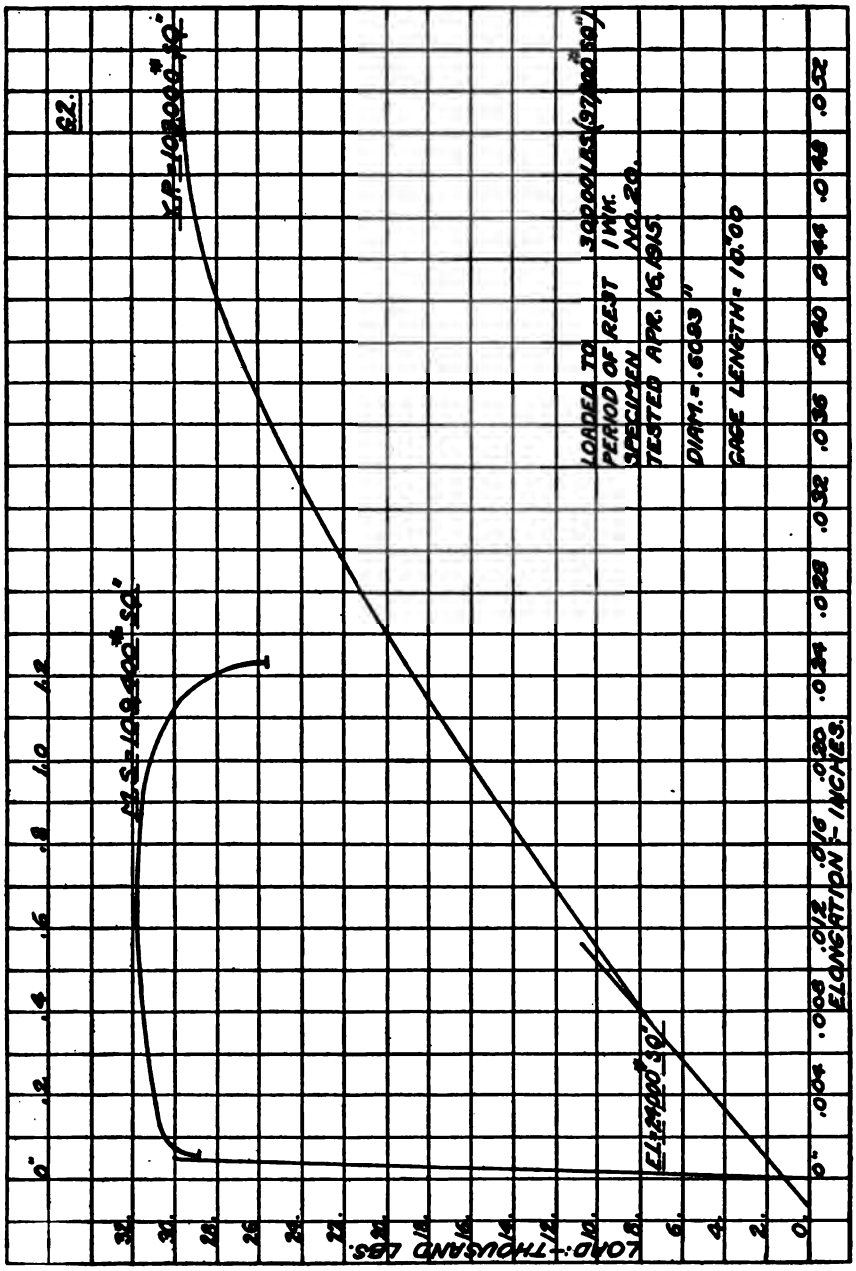
Load.	Extensometers.			
	Left.	Right.	Mean.	
			8-inch gauge.	10-inch gauge.
Pounds.	*Inch.*	*Inch.*	*Inch.*	*Inches.*
1,000	0.00000	0.00000	0.00000	0.00000
2,000	.00090	.00090	.00090	.00113
3,000	.00180	.00170	.00175	.00219
4,000	.00280	.00260	.00270	.00338
5,000	.00375	.00365	.00370	.00463
6,000	.00460	.00450	.00455	.00569
7,000	.00565	.00555	.00560	.00700
7,600	.00615	.00610	.006115	.00766
8,200	.00680	.00675	.006775	.00847
9,000	.00755	.00770	.007625	.00953
10,000	.00860	.00880	.00870	.01087
11,000	.00980	.00990	.00985	.01231
12,000	.01095	.01110	.011025	.01391
13,000	.01210	.01220	.01215	.01519
14,000	.01325	.01340	.01330	.01662
16,000	.01570	.01590	.01580	.01976
18,000	.01800	.01830	.01815	.02270
20,000	.02060	.02090	.02075	.02583
22,000	.02320	.02340	.02330	.02914
24,000	.02590	.02620	.02605	.0326
26,000	.02900	.02930	.02915	.0364
28,000	.03280	.03310	.03295	.0412
30,000	.04300	.04340	.0432	.054
				Scale reading.
29,200	.....	.....	.....	0.06
30,000	.....	.....	.....	.065
30,500	.....	.....	.....	.08
31,000	.....	.....	.....	.16
31,400	.....	.....	.....	.25
31,800	.....	.....	.....	.35
32,000	.....	.....	.....	.42
32,100	.....	.....	.....	1.
32,000	.....	.....	.....	1.03
30,000	.....	.....	.....	1.10
29,000	.....	.....	.....	1.18
27,000	.....	.....	.....	1.22


LOAD:-THOUSAND LBS.
ELONGATION,-INCHES.
LOADED TO 30000 LBS.(97200 #"a")
PERIOD OF REST 1 WK.
SPECIMEN NO. 19.
TESTED APR. 20, 1915.
DIAM. = .6105"
GAGE LENGTH = 10.00"
M.S. = 109,200 #"SE"
Y.P. = 102,900 #"SE"
E = 29,500,000 #"SE"

SPECIMEN NO. 20, GROUP G 2.

Loaded to 30,000 pounds.
Period of rest, one week.

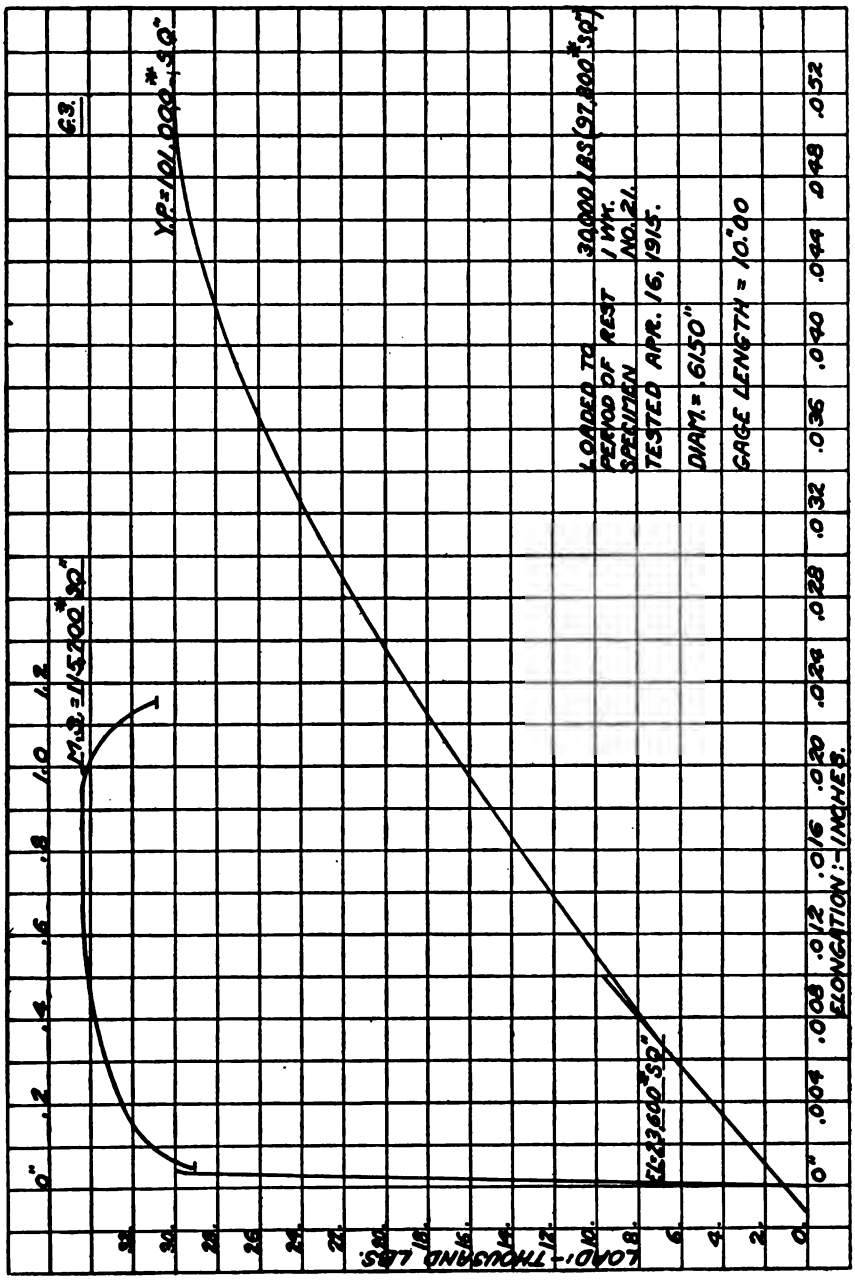
Load.	Extensometers.			
	Left.	Right.	Mean.	
			8-inch gauge.	10-inch gauge.
Pounds.	*Inch.*	*Inch.*	*Inch.*	*Inches.*
1,000	0.00000	0.00000	0.00000	0.00000
2,000	.00090	.00095	.000925	.00115
3,000	.00190	.00180	.001851	.00231
4,000	.00290	.00280	.00285	.00356
5,000	.00375	.00370	.003725	.00466
6,000	.00470	.00465	.004675	.00584
7,000	.00565	.00560	.005625	.00703
8,000	.00670	.00670	.00670	.00838
9,000	.00770	.00775	.007725	.00966
10,000	.00885	.00885	.00885	.01106
11,000	.01000	.01005	.010025	.01253
12,000	.01105	.01115	.01110	.01388
13,000	.01230	.01240	.01235	.01544
14,000	.01340	.01350	.01345	.01681
15,000	.01465	.01465	.01465	.01831
16,000	.01590	.01590	.01590	.01988
18,000	.01835	.01840	.018375	.02297
20,000	.02095	.02090	.020965	.02616
22,000	.02370	.02370	.02370	.02963
24,000	.02640	.02640	.02640	.03300
26,000	.02950	.02960	.02955	.03694
27,000	.03120	.03140	.03130	.03913
28,000	.03130	.03350	.03340	.04175
29,000	.03620	.03620	.03620	.04525
30,000	.04300	.04300	.04300	.05375
				Scale reading.
29,000	.....	.....	.....	0.06
30,000	.....	.....	.....	.065
31,000	.....	.....	.....	.17
31,300	.....	.....	.....	.26
31,600	.....	.....	.....	.40
31,800	.....	.....	.....	.49
31,900	.....	.....	.....	.67
31,800	.....	.....	.....	.86
31,700	.....	.....	.....	.92
28,900	.....	.....	.....	1.18
25,800	.....	.....	.....	1.23


62.
E.P.=10,000 #/SQ.IN.
M.S.=40,000 #/SQ.IN.
LOADED TO 30,000 LBS. (37,500 #/SQ.IN.)
PERIOD OF REST 1 HR.
SPECIMEN NO. 20.
TESTED APR. 16, 1915.
DIAM. = .6043"
GAGE LENGTH = 10.00
E = 29,400,000
LOAD IN THOUSAND LBS.
ELONGATION IN INCHES.

SPECIMEN NO. 21, GROUP G 3.

Loaded to 30,000 pounds.
Period of rest, one week.

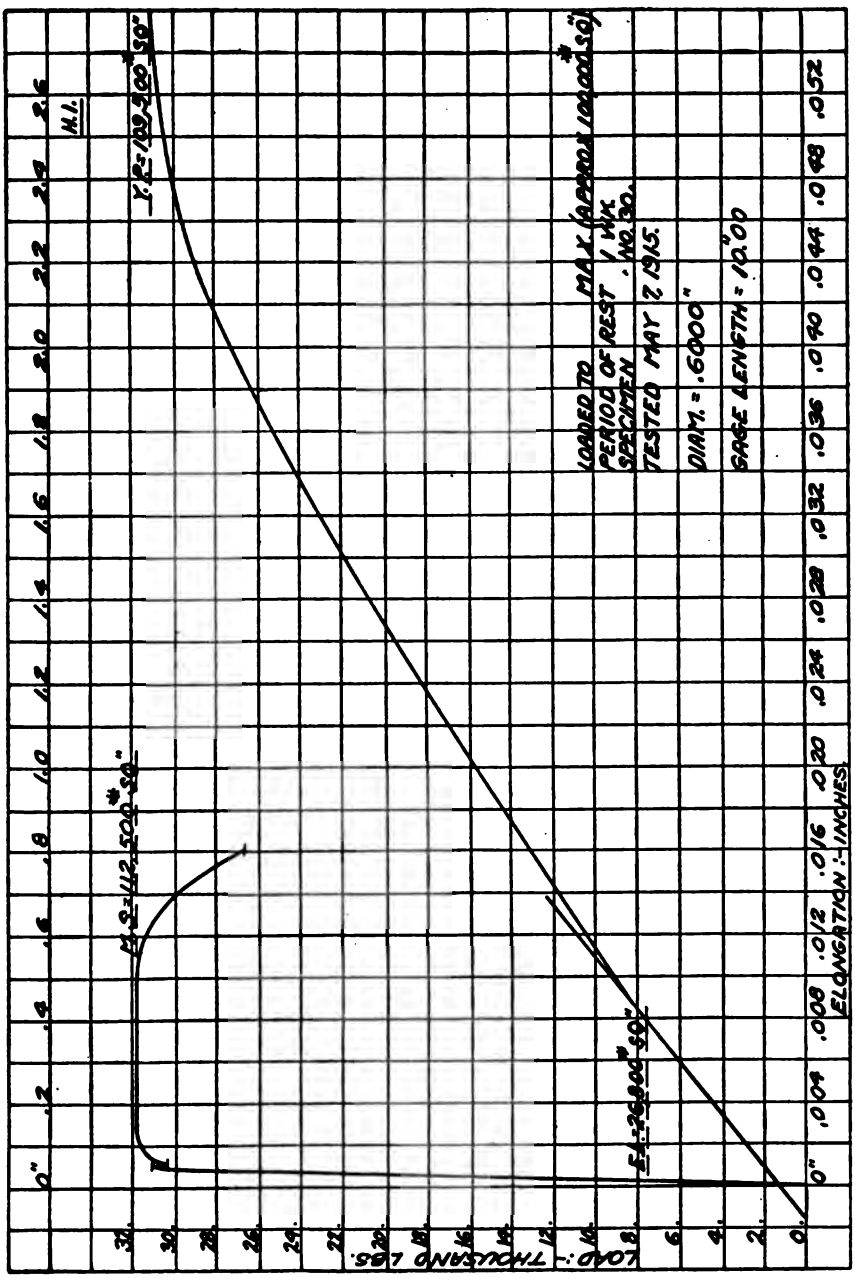
Load.	Extensometers.			
	Left.	Right.	Mean.	
			8-inch gauge.	10-inch gauge.
Pounds.	*Inch.*	*Inch.*	*Inch.*	*Inches.*
1,000	0.00000	0.00000	0.00000	0.00000
2,000	.00090	.00075	.000825	.00103
3,000	.00180	.00170	.00175	.00219
4,000	.00285	.00270	.002775	.00347
5,000	.00375	.00350	.003625	.00453
6,000	.00480	.00440	.00460	.00575
7,000	.00575	.00540	.005575	.00697
8,000	.00675	.00640	.006575	.00822
9,000	.00785	.00740	.007625	.00953
10,000	.00900	.00845	.008725	.01090
11,000	.01010	.00945	.009775	.01222
12,000	.01130	.01065	.010975	.01372
13,000	.01250	.01165	.012075	.01509
14,000	.01375	.01280	.013275	.01659
16,000	.01615	.01500	.015575	.01947
18,000	.01865	.01740	.018025	.02253
20,000	.02120	.01975	.02048	.02560
22,000	.02400	.02220	.0231	.02887
24,000	.02690	.02480	.02585	.03231
26,000	.03030	.02780	.02905	.03631
28,000	.03470	.03100	.03285	.04106
30,000	.0440	.03810	.04100	.05125
				Scale reading.
29,200	.....	.....	.....	.05
30,000	.....	.....	.....	.06
32,000	.....	.....	.....	.15
33,000	.....	.....	.....	.25
33,500	.....	.....	.....	.35
34,000	.....	.....	.....	.47
34,300	.....	.....	.....	.60
34,400	.....	.....	.....	.73
34,000	.....	.....	.....	1.02
32,000	.....	.....	.....	1.13
30,860	.....	.....	.....	.....


LOAD IN THOUSAND LBS.
ELONGATION IN INCHES.
Y.P.=101,000 #/SQ.IN.
M.S.=115,200 #/SQ.IN.
#3
LOADED TO 30000 LBS (97,800 #/SQ.IN.)
PERIOD OF REST 1 WK.
SPECIMEN NO. 21.
TESTED APR. 16, 1915.
DIAM. = .6150"
GAGE LENGTH = 10.00

SPECIMEN NO. 30, GROUP H 1.

Loaded to 31,000 pounds.
Period of rest, one week.

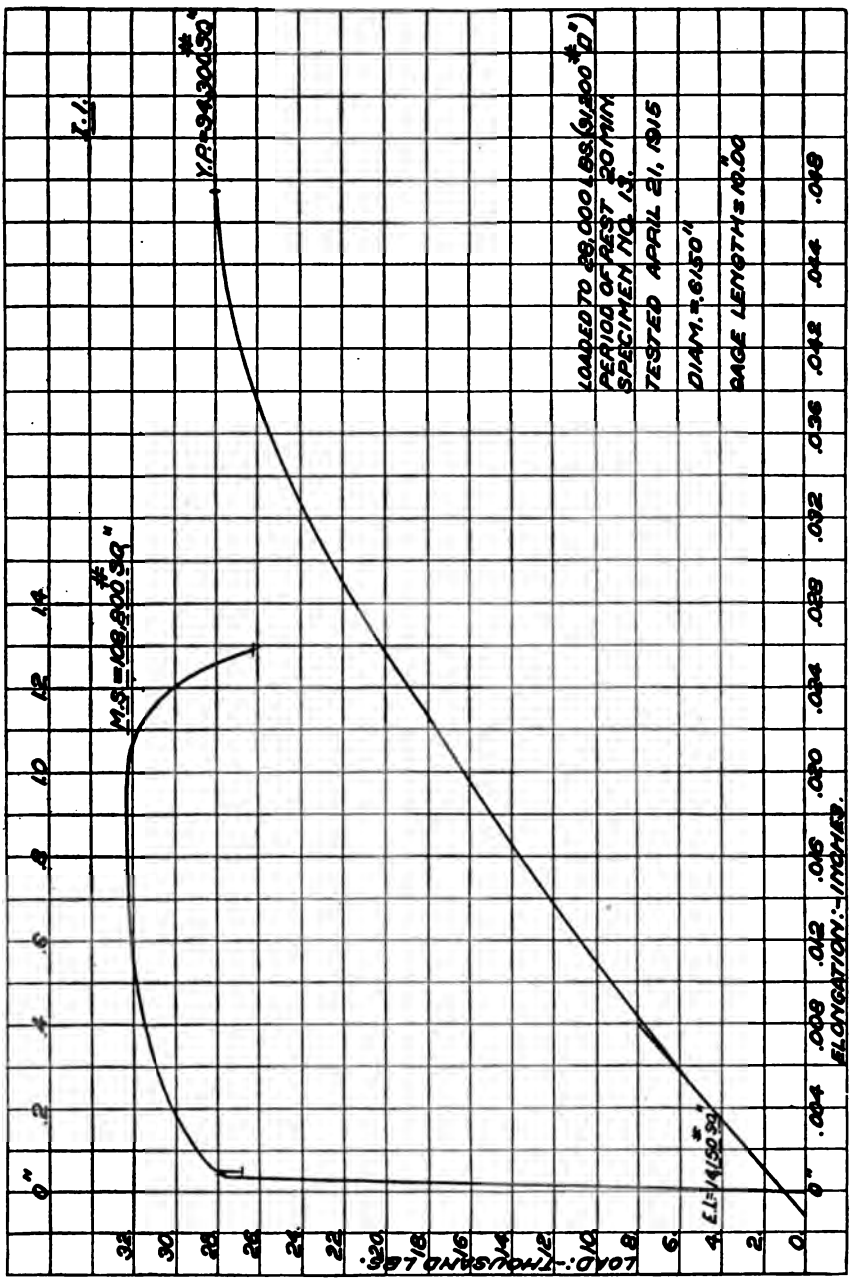
Load.	Extensometers.			
	Left.	Right.	Mean.	
			8-inch gauge.	10-inch gauge.
Pounds.	*Inch.*	*Inch.*	*Inch.*	*Inch.*
1,000	0.00000	0.00000	0.00000	0.00000
2,000	.00090	.00085	.000875	.000109
3,000	.00190	.00180	.00185	.00231
4,000	.00290	.00270	.00280	.00350
5,000	.00410	.00380	.00395	.00494
6.000	.00510	.00460	.00485	.00606
7,000	.00620	.00560	.00590	.00737
8,000	.00730	.00660	.00695	.00868
9,000	.00830	.00765	.007975	.00996
10,000	.00950	.00880	.009150	.01144
11,000	.01060	.01000	.01030	.01287
12,000	.01175	.0120	.011475	
12,000	.01180	.01130	.01155	.01443
14,000	.01430	.01370	.01400	.01750
16,000	.01690	.01610	.01650	.02060
18,000	.01930	.01870	.01900	.02375
20,000	.02180	.02130	.02155	.02695
22,000	.02460	.02410	.02435	.03045
24,000	.027400	.02690	.02715	.03390
26,000	.03030	.02980	.03005	.03755
28,000	.03370	.03340	.03355	.04185
30,000	.03830	.03840	.03835	.04790
30,400	.03980	.03980	.0398	.04975
30,600	.0410	.04140	.0412	.0515
30,800	.0426	.04320	.0429	.0536
31,000	.0445	.04500	.04475	.0560
				Scale reading.
30,300				.06
31,000				.065
31,600				.10
31,700				.25
31,800				.32
31,700				.40
				.50
31,000				.65
30,000				.72
28,000				.78
27,000				.82
26,400				


LOAD :- THOUSAND LBS.
ELONGATION :- INCHES.
0" .004 .008 .012 .016 .020 .024 .028 .032 .036 .040 .044 .048 .052
E1 = 36000 #/□"
E2 = 112,500 #/□"
E3 = 100,000 #/□"
LOADED TO MAX. (APPROX.) 10,000 #/□"
PERIOD OF REST 1 WK.
SPECIMEN NO. 30.
TESTED MAY 2 1915.
DIAM. = .6000"
GAGE LENGTH = 10.00"

SPECIMEN NO. 13, GROUP I 1.

Loaded to 28,000 pounds.
Period of rest, 20 minutes.

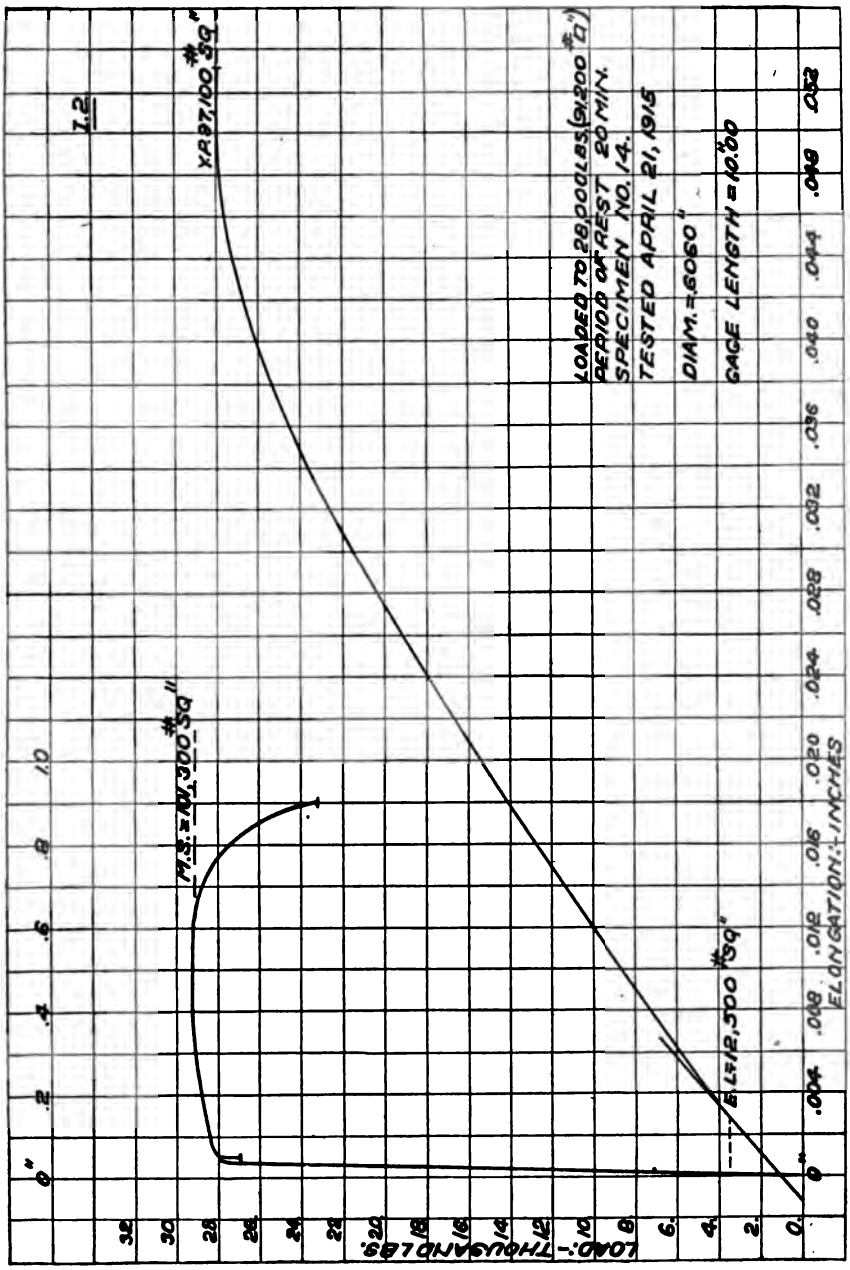
Load.	Extensometers.			
	Left.	Right.	Mean.	
			8-inch gauge.	10-inch gauge.
Pounds.	*Inch.*	*Inch.*	*Inch.*	*Inch.*
1,000	0.00000	0.00000	0.00000	0.00000
2,000	.00080	.00090	.00085	.00106
3,000	.00175	.00185	.00180	.00225
4,000	.00265	.00275	.00270	.00338
5,000	.00365	.00370	.003675	.00459
6,000	.00470	.00475	.004725	.00591
7,000	.00565	.00575	.00570	.00713
8,000	.00675	.00680	.006775	.00847
9,000	.00775	.00785	.00780	.00975
10,000	.00890	.00900	.00895	.01119
11,000	.00995	.01010	.010025	.01253
12,000	.01095	.01115	.01105	.01381
13,000	.01210	.01220	.01215	.01519
14,000	.01335	.01345	.01340	.01675
16,000	.01565	.01570	.015675	.01959
18,000	.01810	.01820	.01815	.02269
20,000	.02050	.02060	.02055	.02569
22,000	.02315	.02330	.02323	.02904
24,000	.02610	.02620	.02615	.03269
26,000	.02970	.02990	.02980	.03725
27,000	.03240	.03260	.03250	.04062
28,000	.03800	.03800	.03800	.04750
				Scale reading.
27,100	.....	.....	.....	0.05
28,000	.....	.....	.....	.055
29,000	.....	.....	.....	.10
30,000	.....	.....	.....	.18
31,000	.....	.....	.....	.32
31,500	.....	.....	.....	.41
32,000	.....	.....	.....	.55 / .65
32,200	.....	.....	.....	.72
32,300	.....	.....	.....	.95
31,000	.....	.....	.....	1.16
29,000	.....	.....	.....	1.23
26,200	.....	.....	.....	1.29


LOADED TO 38,000 LBS (41,800 #/□")
PERIOD OF REST 20 MIN
SPECIMEN NO. 13.
TESTED APRIL 21, 1915
DIAM. = 0.650"
GAGE LENGTH = 10.00"
M.S. = 109,800 #/SQ"
Y.P. = 94,300 #/SQ"
E.L. = 41,150 #/SQ"
LOAD IN THOUSANDS OF LBS.
ELONGATION IN INCHES.

SPECIMEN NO. 14, GROUP I 2.

Loaded to 28,000 pounds.
Period of rest, 20 minutes.

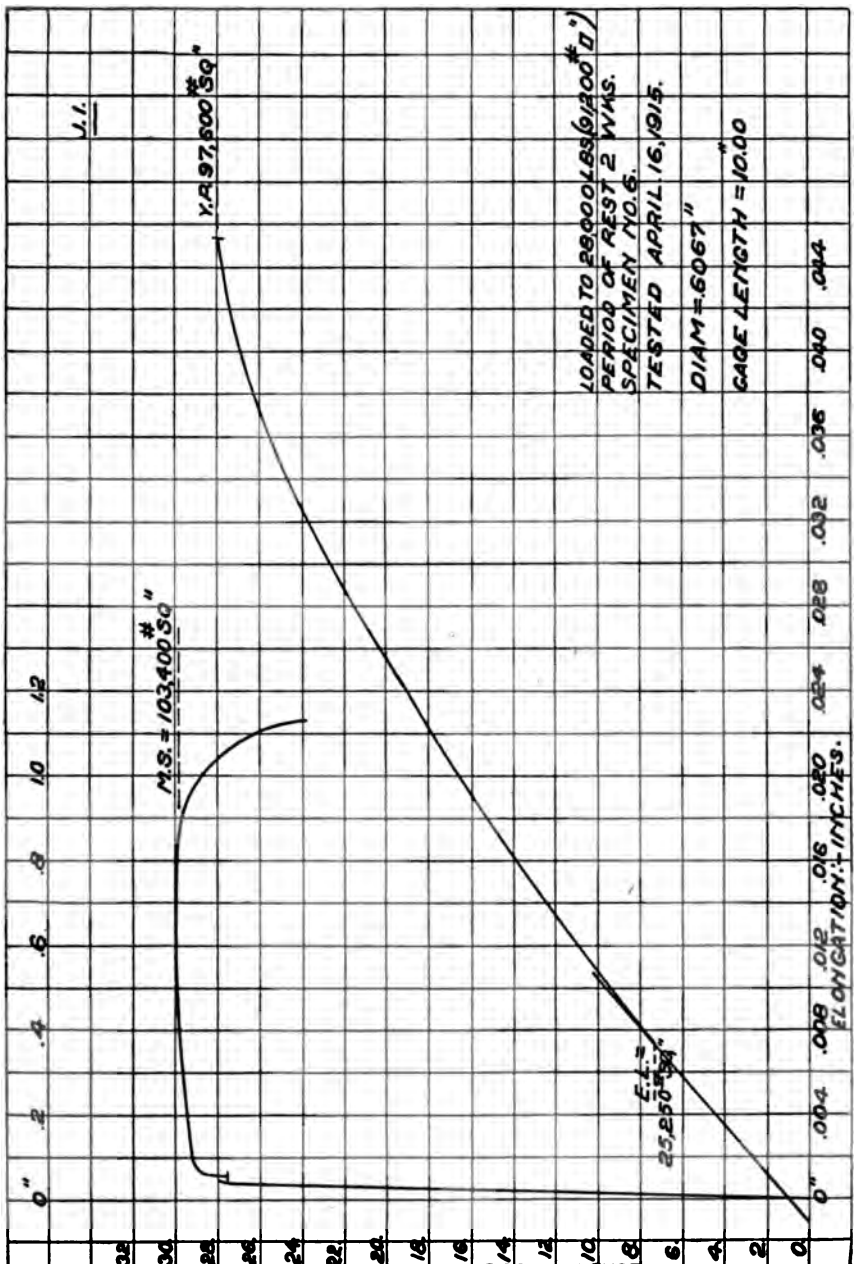
Load.	Extensometers.			
	Left.	Right.	Mean.	
			8-inch gauge.	10-inch gauge.
Pounds.	*Inch.*	*Inch.*	*Inch.*	*Inch.*
1,000	0.00000	0.00000	0.00000	0.00000
2,000	.00085	.00095	.00090	.00113
3,000	.00180	.00190	.00185	.00231
4,000	.00290	.00295	.002925	.00366
5,000	.00390	.00400	.00395	.00494
6,000	.00495	.00515	.00505	.00631
7,000	.00605	.00625	.00615	.00768
8,000	.00715	.00740	.007275	.00909
9,000	.00835	.00865	.00850	.01063
10,000	.00945	.00970	.009575	.01196
11,000	.01055	.01080	.010675	.01334
12,000	.01190	.01215	.012025	.01503
13,000	.01300	.01330	.01315	.01643
14,000	.01430	.01460	.01445	.01806
16,000	.01680	.01705	.016925	.02115
18,000	.01920	.01950	.01935	.02420
20,000	.02190	.02230	.02210	.02765
22,000	.02450	.02500	.02475	.03095
24,000	.02770	.02930	.02800	.0350
26,000	.03170	.03230	.03200	.0400
27,000	.03430	.03500	.03475	.0434
28,000	.04200	.04300	.04250	.0531
				Scale reading.
26,900	.....	.....	.....	0.055
28,000	.....	.....	.....	.06
29,000	.....	.....	.....	.27
29,200	.....	.....	.....	.40
28,000	.....	.....	.....	.77
26,000	.....	.....	.....	.86
23,200	.....	.....	.....	.90


T.2
X AT 97,100 #/SQ"
M.S. = 101,300 #/SQ"
LOADED TO 28,000 LBS. (91,200 #/SQ")
PERIOD OF REST 20 MIN.
SPECIMEN NO. 14.
TESTED APRIL 21, 1915
DIAM. = .6050"
GAGE LENGTH = 10.00"
E = 12,300 #/SQ"
LOAD :- THOUSAND LBS.
ELONGATION :- INCHES

SPECIMEN NO. 6, GROUP J 1.

Loaded to 28,000 pounds.
Period of rest, two weeks.

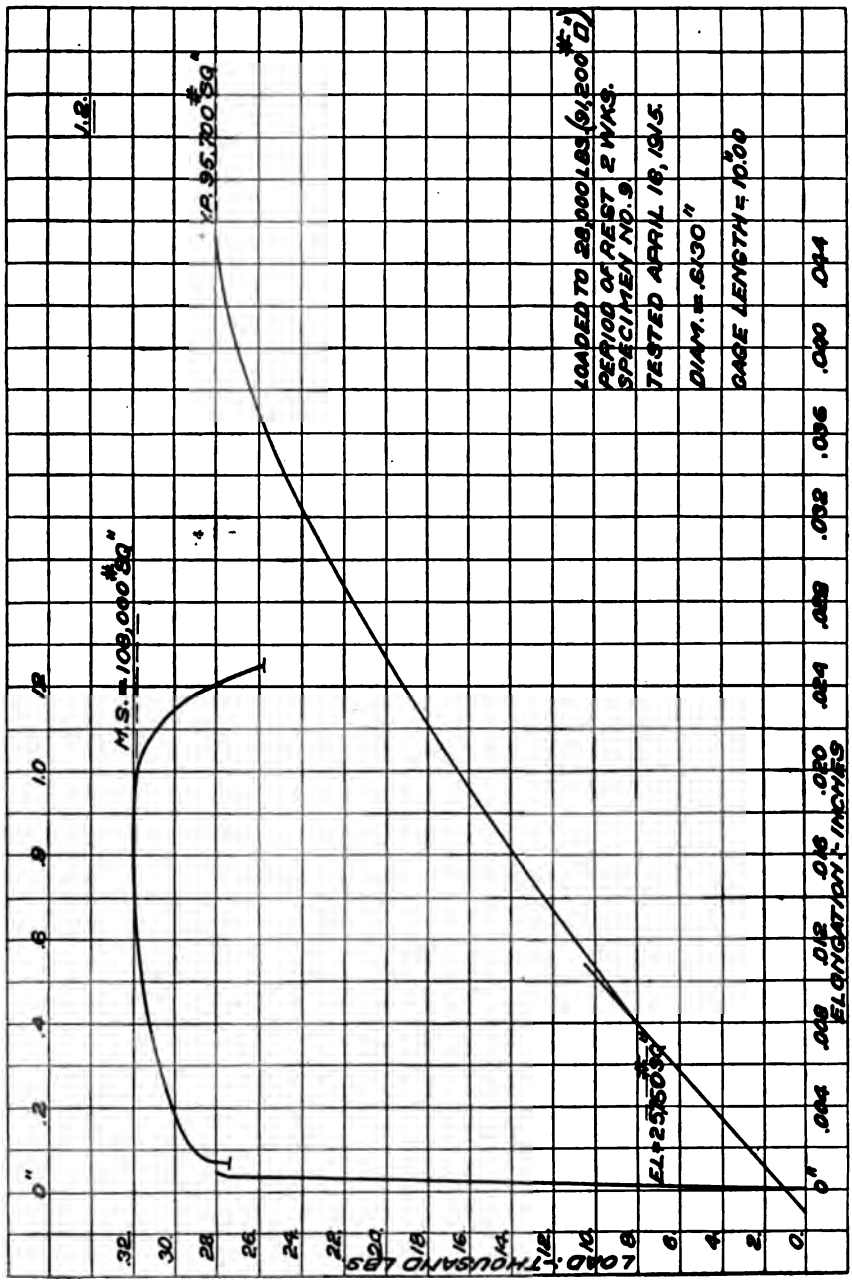
Load.	Extensometers.			
	Left.	Right.	Mean.	
			8-inch gauge.	10-inch gauge.
Pounds.	*Inch.*	*Inch.*	*Inch.*	*Inches.*
1,000	0.00000	0.00000	0.00000	0.00000
2,000	.00100	.00090	.00095	.00119
3,000	.00195	.00170	.001825	.00228
4,000	.00290	.00260	.00275	.00344
5,000	.00390	.00360	.00375	.00469
6,000	.00490	.00440	.00465	.00581
7,000	.00585	.00535	.00560	.00700
8,000	.00690	.00640	.00665	.00831
9,000	.00790	.00730	.00760	.00950
10,000	.00900	.00835	.008675	.01084
11,000	.01000	.00940	.00970	.01213
12,000	.01110	.01040	.01075	.01344
13,000	.01220	.01140	.01180	.01475
14,000	.01340	.01250	.01295	.01619
15,000	.01455	.01380	.014175	.01772
16,000	.01570	.01475	.015225	.01903
17,000	.01705	.01600	.016525	.02066
18,000	.01840	.01730	.01785	.02230
20,000	.02100	.01980	.02040	.0255
22,000	.02360	.02240	.02300	.0282
24,000	.02640	.02530	.02585	.0323
26,000	.03040	.02890	.02965	.0370
28,000	.03740	.03490	.03615	.0451
28,000	.04100	.03830	.03965	.0495
				Scale reading.
27,600	.....	.....	.....	.05
28,000	.....	.....	.....	.06
29,000	.....	.....	.....	.07
29,830	.....	.....	.....	.....
29,830	.....	.....	.....	.48
29,930	.....	.....	.....	.67
29,750	.....	.....	.....	.85
29,500	.....	.....	.....	.93
29,000	.....	.....	.....	1.00
28,000	.....	.....	.....	1.03
27,000	.....	.....	.....	1.06
26,000	.....	.....	.....	1.10
24,000	.....	.....	.....	1.13


LOADED TO 28000 LBS (6,200 #/□")
PERIOD OF REST 2 WKS.
SPECIMEN NO. 6.
TESTED APRIL 16, 1915.
DIAM = .6067"
GAGE LENGTH = 10.00"
Y.P. 97,600 #/SQ"
M.S. = 103400 #/SQ"
E.L. = 25,250 #/SQ"
LOAD IN THOUSAND LBS.
ELONGATION IN INCHES.

SPECIMEN NO. 9, GROUP J 2.

Loaded to 28,000 pounds.
Period of rest, two weeks.

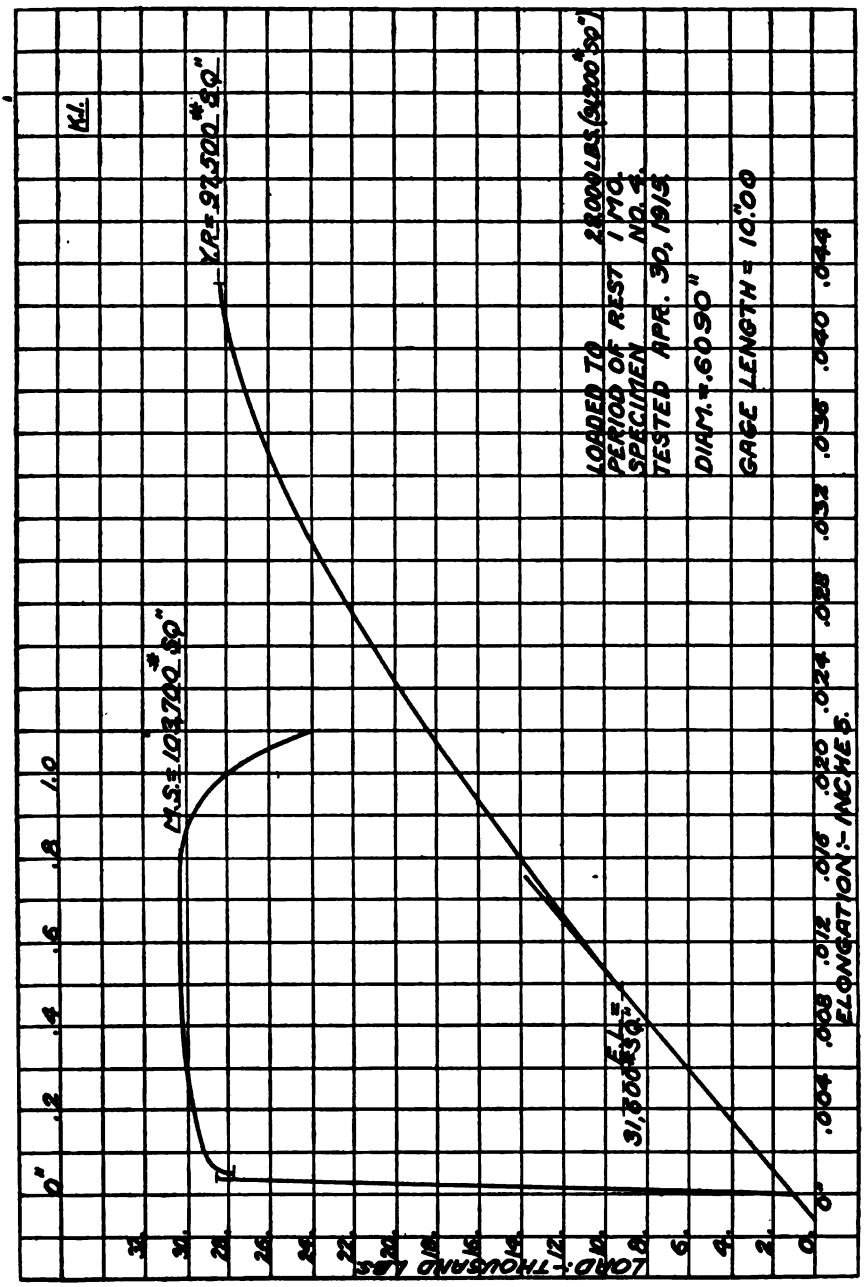
Load.	Extensometers.			
	Left.	Right.	Mean.	
			8-inch gauge.	10-inch gauge.
Pounds.	*Inch.*	*Inch.*	*Inch.*	*Inches.*
1,050	0.00000	0.00000	0.00000	0.00000
2,050	.00100	.00090	.00095	.00119
3,000	.00185	.00175	.00180	.00225
4,000	.00275	.00265	.00270	.00338
5,000	.00365	.00360	.003625	.00453
6,000	.00455	.00455	.00455	.00569
7,000	.00540	.00550	.00545	.00681
8,000	.00640	.00645	.006425	.00803
9,000	.00745	.00750	.007475	.00934
10,000	.00845	.00860	.008525	.01066
11,000	.00940	.00960	.009500	.01188
12,000	.01055	.01075	.01065	.01331
13,000	.01160	.01190	.01175	.01469
14,000	.01275	.01300	.012875	.01609
15,000	.01395	.01415	.01405	.01756
16,000	.01510	.01640	.01675	.....
18,000	.01755	.01775	.01765	.02206
20,000	.02015	.02035	.02025	.02531
22,000	.02280	.02310	.02295	.0287
24,000	.02580	.02620	.02600	.0325
26,000	.02910	.02960	.02935	.0367
28,000	.03560	.03620	.03690	.0448
28,000	.04560	.04640	.04600	.0575
				Scale eading.
27,400	.....	.....	.....	.06
28,000	.....	.....	.....	.07
29,000	.....	.....	.....	.10
30,000	.....	.....	.....	.18
30,400	.....	.....	.....	.25
31,000	.....	.....	.....	.35
31,400	.....	.....	.....	.45
31,600	.....	.....	.....	.54
31,800	.....	.....	.....	.63
31,900	.....	.....	.....	.90
.....	.....	.....	.....	.90
31,700	.....	.....	.....	1.00
31,400	.....	.....	.....	1.06
31,000	.....	.....	.....	1.09
28,000	.....	.....	.....	1.20
25,800	.....	.....	.....	1.25


LOADED TO 29,000 LBS (91,200 #/□")
PERIOD OF REST 2 WKS.
SPECIMEN NO. 9
TESTED APRIL 18, 1915.
DIAM. = .6230"
GAGE LENGTH = 10.00"
M.S. = 109,000 #/□"
Y.P. 95,200 #/□"
EL. = 25,000 #/□"
LOAD - THOUSAND LBS
ELONGATION - INCHES

SPECIMEN NO. 4, GROUP K 1.

Loaded to 28,000 pounds.
Period of rest, four weeks.

Load.	Extensometers.			
	Left.	Right.	Mean.	
			8-inch gauge.	10-inch gauge.
Pounds.	*Inch.*	*Inch.*	*Inch.*	*Inches.*
1,000	0.00000	0.00000	0.00000	0.00000
2,000	.00105	.00095	.00100	.00125
3,000	.00190	.00180	.00185	.00231
4,000	.00290	.00280	.00280	.00350
5,000	.00385	.00375	.00380	.00475
6,000	.00470	.00470	.00470	.00588
7,000	.00565	.00575	.00570	.00713
8,000	.00660	.00670	.00665	.00831
9,000	.00775	.00775	.00775	.00969
10,000	.00865	.00875	.00870	.01087
11,000	.00975	.00975	.00975	.01219
12,000	.01065	.01060	.010625	.01328
13,000	.01170	.01165	.011675	.01459
14,000	.01270	.01270	.01270	.01587
15,000	.01370	.01370	.01370	.01712
17,000	.01590	.01590	.01590	.01987
19,000	.01825	.01815	.01820	.02275
21,000	.02075	.02050	.02063	.02579
23,000	.0233	.02310	.02320	.02900
25,000	.02625	.02615	.02620	.03275
26,000	.02820	.02810	.02815	.03519
27,000	.03020	.03010	.03015	.03669
27,600	.03160	.03150	.03155	.03944
28,000	.03340	.03310	.03325	.04156
28,400	.03520	.03500	.03510	.04588
				Scale reading.
27,800	.....	.....	.....	0.045
29,000	.....	.....	.....	.05
29,400	.....	.....	.....	.19
29,800	.....	.....	.....	.31
30,000	.....	.....	.....	.40
30,200	.....	.....	.....	.54
30,200	.....	.....	.....	.75
30,000	.....	.....	.....	.85
28,000	.....	.....	.....	1.00
26,000	.....	.....	.....	1.06
24,000	.....	.....	.....	1.10


LOADED TO 18000 LBS (91200 #/SQ")
PERIOD OF REST 1 MO.
SPECIMEN NO. 4.
TESTED APR. 30, 1913
DIAM. = .6090"
GAGE LENGTH = 10.00"
Y.P. = 91,520 #/SQ"
M.S. = 103,700 #/SQ"
E = 31,300,000 #/SQ"
LOAD :- THOUSAND LBS.
ELONGATION :- INCHES.

SPECIMEN NO. 10, GROUP K 2.

Loaded to 28,000 pounds.
Period of rest, four weeks.

Load.	Extensometers.			
	Left.	Right.	Mean.	
			8-inch gauge.	10-inch gauge.
Pounds.	*Inch.*	*Inch.*	*Inch.*	*Inches.*
1,000	0.00000	0.00000	0.00000	0.00000
2,000	.00090	.00080	.00085	.00106
3,000	.00185	.00175	.00180	.00225
4,100	.00285	.00280	.002825	.00353
5,000	.00365	.00360	.003625	.00453
6,000	.00460	.00460	.00460	.00575
7,000	.00560	.00560	.00560	.00700
8,000	.....	.....	.....	.....
8,400	.00685	.00695	.00690	.00863
8,600	.00700	.00710	.00705	.00881
9,000	.00735	.00755	.00745	.00931
10,000	.00830	.00860	.00845	.01056
11,000	.00920	.00960	.00940	.01175
12,000	.01020	.01070	.01045	.01306
13,000	.01120	.01180	.01150	.01437
14,000	.01220	.01275	.012475	.01559
15,000	.01320	.01380	.01350	.01687
17,000	.01545	.01600	.015725	.01966
19,000	.01780	.01850	.01815	.02270
21,000	.02010	.0210	.02055	.0257
23,000	.0227	.0238	.02325	.0290
25,000	.0260	.0272	.02660	.0332
27,000	.0297	.0313	.03050	.0381
27,600	.0312	.0329	.03205	.0401
28,000	.0327	.0345	.03360	.0420
28,400	.0348	.0367	.03575	.0447
				Scale reading.
27,800	.....	.....	.....	0.05
29,000	.....	.....	.....	.06
29,200	.....	.....	.....	.21
29,600	.....	.....	.....	.36
29,800	.....	.....	.....	.49
29,800	.....	.....	.....	.67
29,000	.....	.....	.....	.86
28,000	.....	.....	.....	.95
26,000	.....	.....	.....	1.02
23,000	.....	.....	.....	1.07

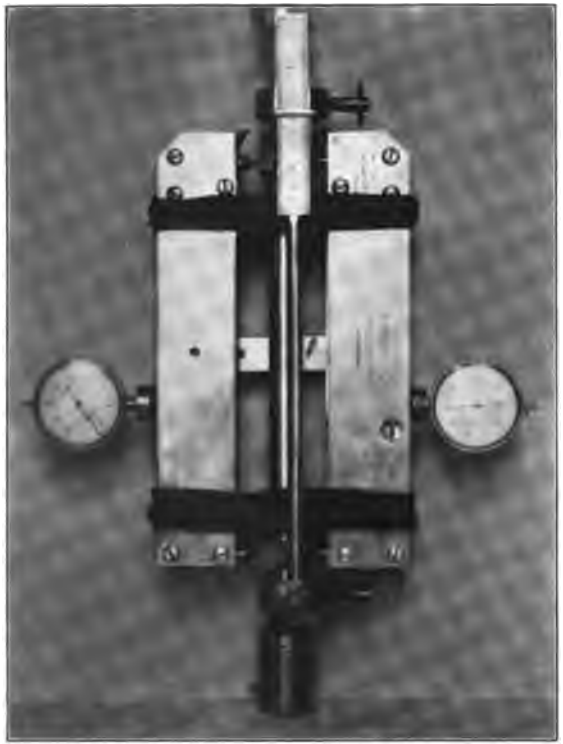


FIG. 1.

Specimen assembled for test. Front view, showing Berry extensometers and scale extensometer.

FIG. 2.

Specimen assembled for test. Back view, showing Berry extensometers and scale extensometer.

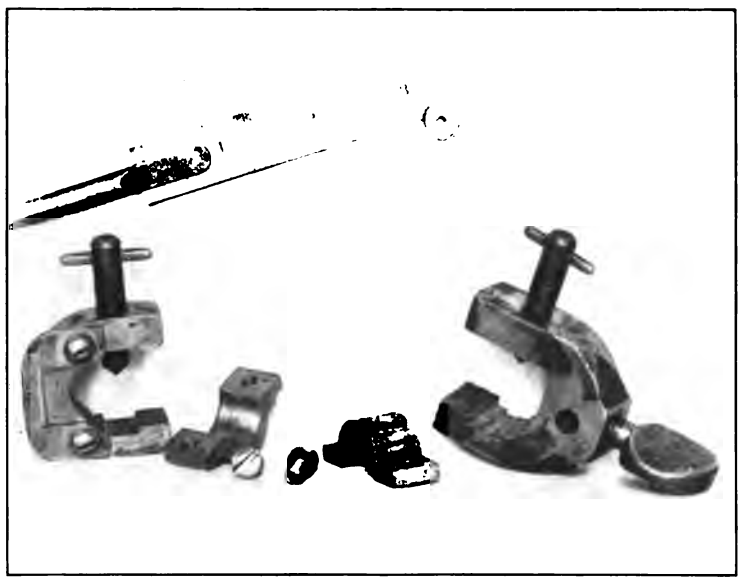
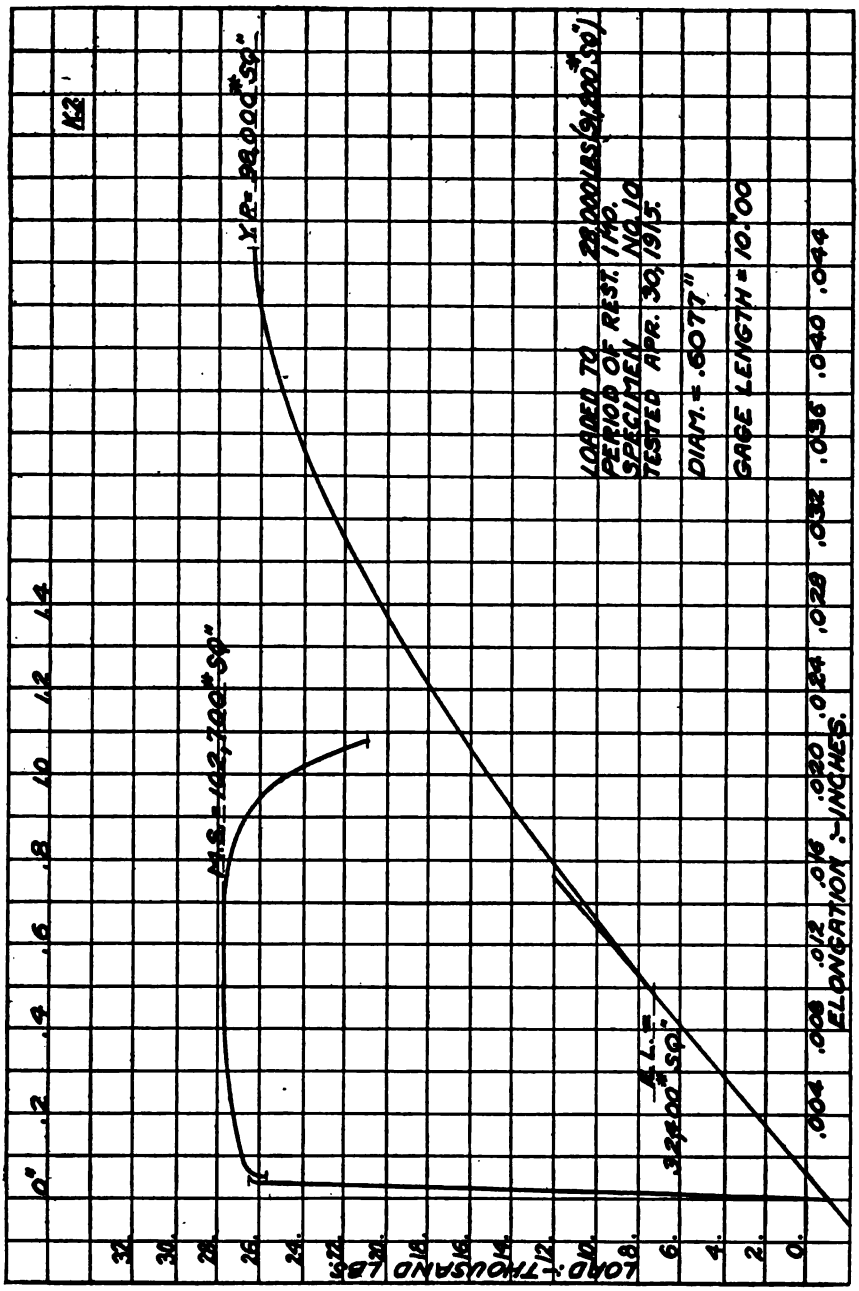


FIG. 3.

Showing special parts of the extensometer apparatus before assembling on a specimen.


LOWER TY
PERIOD OF REST. 1½ hrs.
SPECIMEN
TESTED APR. 30, 1915
DIAM. = .607"
GAGE LENGTH = 10.00
LOAD - THOUSAND LBS.
ELONGATION - INCHES.

HEAT TREATMENT OF STEEL.

HEAT TREATMENT OF HYPOEUTECTOID CARBON STEEL CASTINGS.

The following report covers an investigation of the heat treatment of hypoeutectoid carbon steel castings.

Prof. H. M. Howe's recommended practice, as quoted from his paper on the subject, is as follows:

RECOMMENDED PRACTICE.

Heat to somewhat above Ac3, to temperatures varying with the carbon content, as follows:

C. per cent.	Temperature, degrees C.
Up to .12	875–925
.12 to .29	840–875
.30 to .49	815–840
.50 to 1.00	790–815

for from two to four hours; or heat to some 1,200° C. for a few minutes, cool in air, and reheat to temperatures above Ac3. After these heatings, cool at rates varying with the size, shape, and carbon content of the piece, and with the physical properties it is desired to give the steel.

This practice varies chiefly in only one detail from that in use at this arsenal. This point of variance is, that after the removal of ingotism has been accomplished by a heating above the Ac3 point, followed by an air chill, the pieces are then reheated to a point just above the Ac1 point, whereas Prof. Howe's practice recommends that this second heating shall be carried above the Ac3. The principal point for investigation then was to find out which of these two methods of reheating resulted in better physical properties. The program laid out to accomplish this was as follows:

Cast in one dry sand mold a slab 16 by 10 by 2½ inches of our regular No. 3 cast steel, approximating C. 0.45, Mn. 0.60. Let cool in mold and cut up in pieces 5 by 1 by 1 inch. Make chemical analyses and micrographs of the metal as cast.

Heat six bars to 1,200° C. for a few minutes and cool in air. Make a micrograph. Heat 12 bars to just above Ac3 and hold for two hours, then cool in air. Make a micrograph.

Of these last 12 bars, reheat six just above Ac3 and quench three in oil and three in air; reheat the second six just above Ac1 and quench three in oil and three in air. Make micros.

Test two of each set in tension and make Charpy impact bars from the other of each set.

Depending upon the results of physical tests of the last 12 bars, give the first six bars a suitable heat treatment; that is, quench in air and oil from just above the Ac3 or Ac1, depending on which quenching temperature gives the best physical properties.

The program, as planned, was carefully carried out. Chemical analysis showed the composition to be as follows:

	Per cent.
Carbon	0.48
Manganese	.66
Silicon	.285
Sulphur	.047
Phosphorus	.028

The heat-treating operations were carefully done in small electrically heated muffle furnaces. Temperatures were registered by means of calibrated rare metal couples, and the laboratory Leeds & Northrup precision potentiometer.

The specimens were then machined and tested, and the results are reported in Tables I, II, and III. Table I gives the complete tensile and hardness results; Table II gives complete Charpy impact test results, and Table III gives the average values of all tests.

An examination of the tables will show that for this steel (C. 0.48 per cent, Mn. 0.66 per cent) there is practically no difference in the resulting physical properties, whether the steel is cooled from above the Ac3 or the Ac1 point. For instance, in Table III, consider the specimens H 7, 8, and 9, in comparison with those marked H 10, 11, and 12. These pieces were oil quenched from 825° C. and 760° C., respectively, and what slight difference there is seems to be in favor of the specimens cooled from the lower temperature. The strength and resistance to shock are slightly higher for the specimens oil quenched from 760° C. than for those oil quenched from 825° C., while the ductility figures are the same for both.

In the case of the air-cooled specimens, the preference seems to be with the specimens cooled from 825° C., though in this case the advantage is in ductility rather than strength or resistance to shock. The amount of variance in all cases is small, and seems to point to the conclusion that for steel of this carbon content it is immaterial whether the quenching be done from above the Ac3 or the Ac1. It must be remembered, however, that for steel of this carbon content (C. 0.48) the Ac1 point and the Ac3 are very close together; and the difference in the effect produced by quenching from above the one or the other is not as marked as it would be in steels of lower carbon.

As regards the two methods of heating for removal of ingotism, recommended by Prof. Howe, viz, heating to 1,200° C. for a few minutes, or heating to above the Ac3 point for two to four hours, specimens H 1, 2, and 3 may be compared with H 7, 8, and 9, and specimens H 4, 5, and 6 with H 13, 14, and 15, Table III. It will be observed in the case of the oil-quenched specimens that the ones deingotized by the high heat are somewhat better in strength and resistance to shock than those heated just above Ac3 for a longer time, while ductility is not effected. On the contrary, in the case of the air-cooled pieces, specimens H 4, 5, and 6 are slightly inferior to specimens H 13, 14, and 15 in all properties except resistance to shock. The amount of variation, however, is small in all cases, and the removal of ingotism seems to have been accomplished equally well in both cases.

It will be noted that none of the steels as treated develop the physical properties specified for cast steel No. 3. Specimens H 13, 14, and 15 in Table III give the best results, and if followed by the usual drawing below Ac1 would show satisfactory physical qualities for cast steel No. 3. The microphotographs made in connection with this investigation are interesting and instructive, and, together with a discussion, are appended hereto.

Photograph No. 1 is in the original cast condition of the metal and is a characteristic coarse structure. Photographs No. 2 and No. 3 were taken from specimens H 8 and H 10, respectively. After having

had the casting structure removed by an 825° C. heat for two hours, followed by air cooling, they were then oil quenched from respectively 825° C. for H 8 (photograph No. 2) and 760° C. for H 10 (photograph No. 3). The microstructures are interesting. Both show closegrained sorbite with fine grain boundaries of ferrite. Photograph No. 2 shows that complete solution of the primary constituents of the steel was accomplished by the 825° C. heating before quenching. No traces of a primary ferrite network is visible, though evidences of incomplete diffusion are present.

Heating for a longer time than 15 minutes would have caused complete diffusion of the dissolved ferrite, thus eliminating the localized white patches seen in photograph No. 2. In photograph No. 3, however, traces of the primary ferrite network persist, showing that complete solid solution was not attained by the 760° C. heating before quenching. The same remarks as to structure hold for photographs No. 4 and No. 5, though in this case the constituents are pearlite and ferrite, instead of sorbite and ferrite. Also photograph No. 4 does not show evidences of incomplete diffusion as does photograph No. 2, because of the longer time allowed by air cooling for diffusion to take place.

In short, photographs Nos. 2, 3, 4, and 5 show that heating above Ac3 causes all excess ferrite to be redissolved, while heating only above Ac1 leaves traces of the primary network of excess ferrite undissolved. Photographs No. 6 and No. 7, respectively oil and air cooled from 825° C. after a preliminary deingotizing heat of 1,200° C., may be compared with photographs No. 2 and No. 3. The structure is not very different from these two, and all effect of the 1,200° C. heat appears to be eliminated. Photograph No. 6 shows that insufficient time was allowed at the hardening heat for complete diffusion to complete itself.

These microphotographs agree with modern theory, and indicate that the best results can be obtained by heating the second time above Ac3.

CONCLUSIONS.

From physical tests made, the conclusion is evident that no great differences in physical properties result for steel of this chemical composition, whether heating for hardening is carried just above the Ac1 or Ac3. This slight difference undoubtedly results from the fact that the Ac1 and the Ac3 points are very close together for steel of this carbon content.

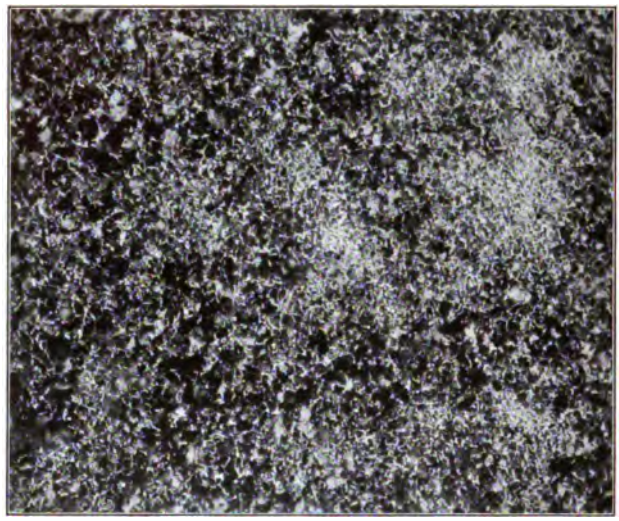
Microscopic evidence shows that the solution of ferrite is not completed until the Ac3 is passed, and consequently the best results are obtained by heating above this point.

The conclusion, therefore, is that Prof. H. M. Howe's recommended practice is correct and likewise is suitable for conditions at this arsenal. In order to put this recommended practice into operation with as great saving in time and cost as possible, the following procedure is recommended:

(1) Removal of ingotism. Heat two to four hours just above the Ac3 point (the shorter time for light castings, the Ac3 point depending on the carbon content of the steel. Air chill by pulling car from furnace until casting loses color.

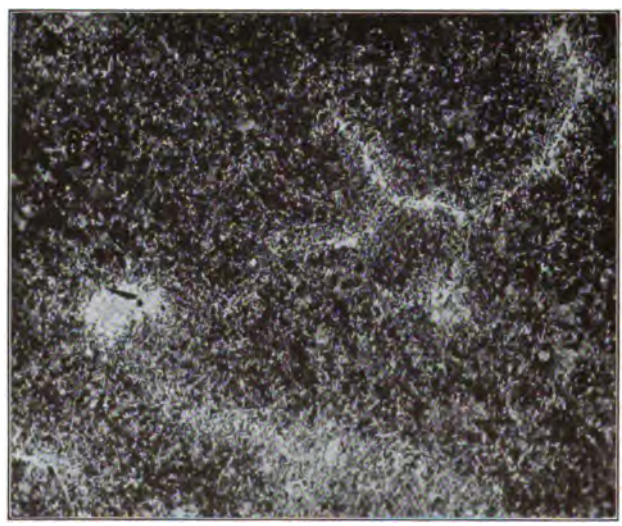
(2) Second heat. Immediately run castings back into furnace and heat just above the Ac3 for one hour. Air chill by pulling car from furnace until castings lose color.

PHOTOGRAPH NO. 1. (X75.)
As cast.



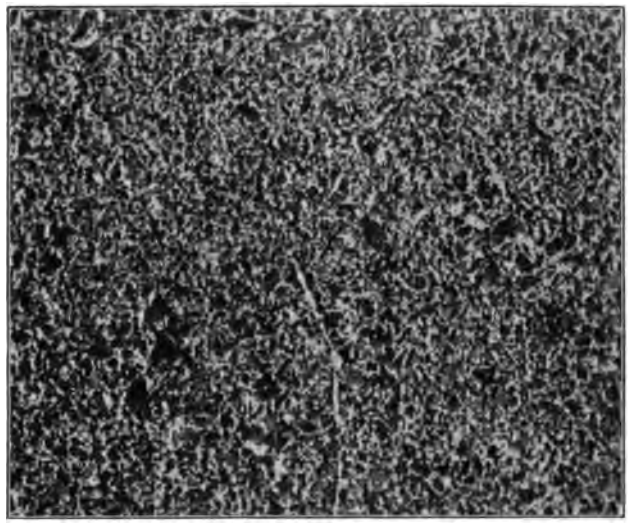
PHOTOGRAPH NO. 2. (X75.)

H8. Heated two hours at 825° C. and air cooled. Then heated to 825° C., held 15 minutes and oil quenched.



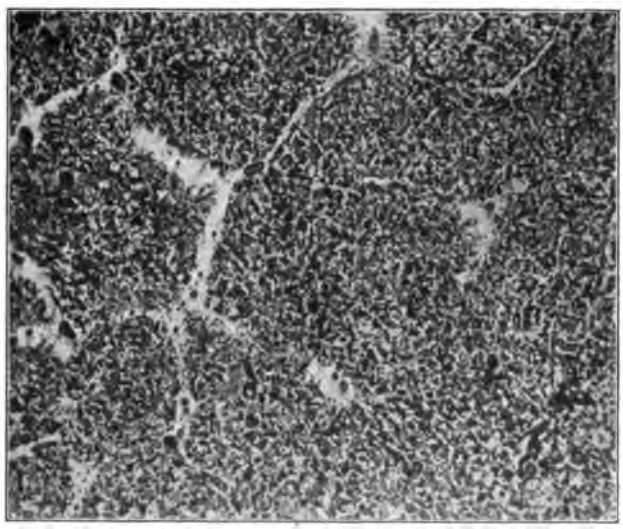
PHOTOGRAPH NO. 3. (X75.)

H10. Heated two hours at 825° C. and air cooled. Then heated to 760° C., held 15 minutes and oil quenched.



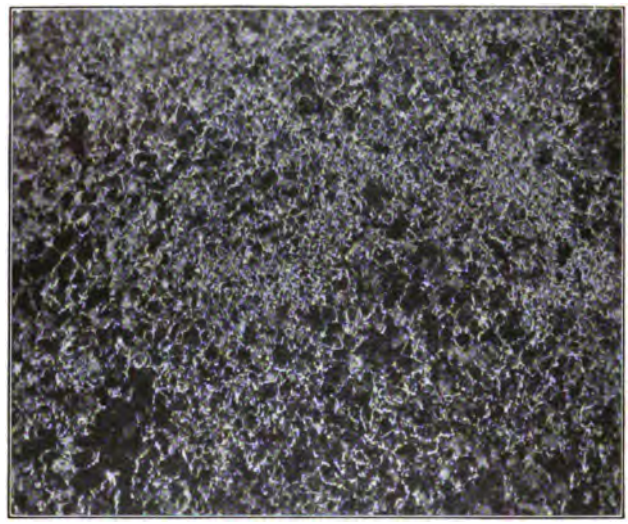
PHOTOGRAPH NO. 4. (X75.)

H14. Heated two hours at 825° C., running up to 920° C. for a few minutes, then air cooled. Then heated to 825° C., held 15 minutes and air cooled.



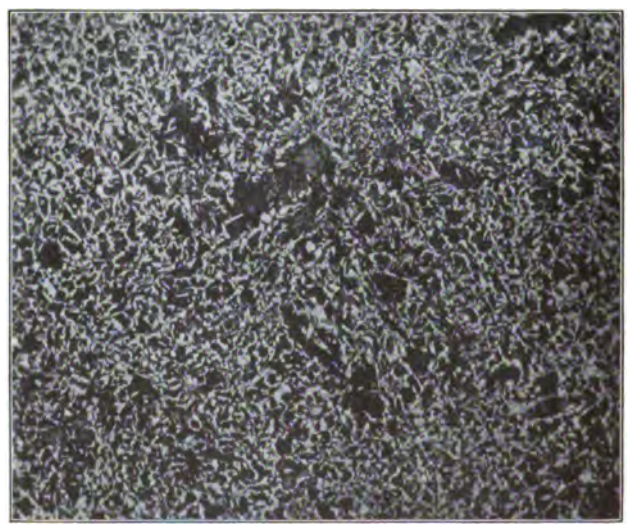
PHOTOGRAPH NO. 5. (X75.)

H16. Heated two hours at 825° C., running up to 920° C. for a few minutes, then air cooled. Then heated to 825° C., held 15 minutes and air cooled.



PHOTOGRAPH NO. 6. (X75.)

H2. Heated to 1,200° C. and air cooled. Heated to 825° C. for 15 minutes and quenched in oil.



PHOTOGRAPH NO. 7. (X75.)

H4. Heated to 1,200° C. and air cooled. Heated to 825° C. for 15 minutes and air cooled.

(3) Drawing operation. Run car back into furnace and draw one to two hours at 500° C., or temperature which will give the desired physical properties.

TABLE I.—*Tensile tests.*

Mark.	Elastic limit (pounds per square inch).	Tensile strength (pounds per square inch).	Elongation (per cent in 2 inches).	Contraction of area (per cent).	Brinell hardness No.	Character of fracture.	Heat treatment.
H 0 1	40,500	84,500	7.0	13.3	170	Crystalline and flaky..	As cast.
H 0 2	40,000	86,500	6.0	5.7	183	.....do.....	Do.
H 1	84,000	121,500	8.5	13.3	241	Fine granular, 85 per cent; amorphous, 15 per cent.	Heated to 1,200° C. and air cooled. Heated to 825° C. for 15 minutes and oil quenched.
H 2	80,000	113,500	4.5	5.7	228	Fine granular, 80 per cent; amorphous, 20 per cent.	Do.
H 4	55,000	92,500	11.0	16.9	183	Amorphous.....	Heated to 1,200° C. and air cooled. Heated to 825° C. for 15 minutes and air cooled.
H 5	57,500	91,500	10.5	13.3	179	.....do.....	Do.
H 7	81,500	113,000	8.0	9.5	241	Amorphous, with fine granular patch at circumference.	Heated to 825° C. 2 hours, then air chilled. Heated to 825° C. 15 minutes, then oil quenched.
H 8	76,500	106,500	6.0	9.5	228	Amorphous, 30 per cent; fine granular, 70 per cent.	Do.
H 10	82,000	111,500	5.5	5.7	228	Amorphous, with fine granular patch at circumference.	Heated to 825° C., held for 2 hours, and air cooled. Heated to 760° C., held 15 minutes, and oil quenched.
H 11	80,500	116,500	9.0	13.3	228	Amorphous, 60 per cent; fine granular, 40 per cent.	Do.
H 13	60,000	92,000	10.5	16.9	179	Amorphous.....	Heated to 825° C., held 2 hours, and air cooled. Heated to 825° C., held 15 minutes, and air cooled.
H 14	60,500	96,000	16.5	20.5	187	Fine granular, 50 per cent; lamellar, 50 per cent.	Do.
H 16	59,000	87,000	7.5	13.3	196	Amorphous.....	Do.
H 17	60,500	91,500	9.0	13.3	179	Fine granular, 80 per cent; amorphous, 20 per cent.	Do.

TABLE II.—*Charpy impact tests.*

Mark.	Charpy test results (foot-pounds per square inch.)	Heat treatment.
H 0 1	189.0	As cast.
H 0 2	180.0	
H 0 3	194.5	
H 0 4	205.0	
H 0 5	205.0	
H 0 6	178.5	
H 0 7	180.0	
H 0 8	196.0	
H 3 1	256.0	Heated to 1,200° C., air cooled; then heated to 825° C., held 15 minutes, then oil quenched.
H 3 2	231.0	
H 3 3	300.0	
H 3 4	327.5	
H 3 5	300.0	
H 3 6	310.5	
H 3 7	328.0	
H 3 8	241.0	

TABLE II.—*Charpy impact tests*—Continued.

Mark.	Charpy test results (foot-pounds per square inch).	Heat treatment.
H 6 1	321.0	Heated to 1,200° C., then air cooled. Heated to 825° C., held 15 minutes, then air cooled.
H 6 2	231.5	
H 6 3	282.0	
H 6 4	238.5	
H 6 5	265.5	
H 6 6	257.0	
H 6 7	284.0	
H 6 8	284.0	
H 9 1	207.0	Heated to 825° C., held 2 hours, air cooled. Heated to 825° C., held 15 minutes, then oil quenched.
H 9 2	234.0	
H 9 3	242.0	
H 9 4	250.0	
H 9 5	259.0	
H 9 6	215.0	
H 9 7	251.0	
H 9 8	207.0	
H 12 1	240.0	Heated to 825° C., held 2 hours, air cooled. Heated to 760° C., held 15 minutes, then oil quenched.
H 12 2	241.0	
H 12 3	285.0	
H 12 4	233.0	
H 12 5	304.0	
H 12 6	260.0	
H 12 7	267.5	
H 12 8	249.0	
H 15 1	268.0	Heated to 825° C., held 2 hours, air cooled. Heated to 825° C., held 15 minutes, then air cooled.
H 15 2	241.0	
H 15 3	232.0	
H 15 4	241.0	
H 15 5	233.0	
H 15 6	216.0	
H 15 7	207.0	
H 15 8	233.0	
H 18 1	233.0	Heated to 825° C., held 2 hours, air cooled. Heated to 760° C., held 15 minutes, then air cooled.
H 18 2	249.0	
H 18 3	232.0	
H 18 4	198.5	
H 18 5	216.5	
H 18 6	250.0	
H 18 7	230.0	
H 18 8	241.0	

TABLE III.

Mark.	Elastic limit (pounds per square inch).	Tensile strength (pounds per square inch).	Elongation (per cent in 2 inches).	Contraction of area (per cent).	Charpy test (foot-pounds per square inch).	Brinell hardness No.	Heat treatment.
H 0 1, 2, and 3	40,250	85,500	6.5	9.5	191.0	177	As cast.
H 1, 2, and 3	82,000	117,500	6.5	9.5	286.7	235	Heated to 1,200° C., and air cooled, then heated to 825° C., and oil quenched.
H 4, 5, and 6	56,250	92,000	10.75	10.1	264.2	205	Heated to 1,200° C. and air cooled, then heated to 825° C. and air cooled.
H 7, 8, and 9	79,000	109,750	7.0	9.5	233.1	235	Heated to 825° C., held 2 hours, then air cooled, then heated to 825° C. and oil quenched.
H 10, 11, and 12	81,250	114,000	7.5	9.5	259.9	228	Heated to 825° C., held 2 hours, then air cooled, then heated to 760° C. and oil quenched.
H 13, 14, and 15	60,250	94,000	13.5	18.7	233.9	183	Heated to 825° C., held 2 hours, air cooled, heated to 825° C. and then air cooled.
H 16 and 17	59,750	89,500	8.25	13.3	231.2	187	Heated to 825° C., held 2 hours, air cooled, then heated to 760° C. and air cooled.

EFFECT OF DURATION OF DRAWING ON PHYSICAL PROPERTIES OF HARDENED NICKEL STEEL.

OBJECT.

The following experiment was planned and carried out in order to determine the relation existing between the duration of the drawing operation and the resulting physical properties of hardened nickel steel.

CONCLUSIONS.

From this experiment the following conclusions can be drawn:

(1) For pieces about $1\frac{7}{16}$ inches section, and for drawing temperatures around 375° C., a period of one hour's drawing suffices to produce the full effect of reheating to that temperature; longer drawing at that temperature produces no further change in physical properties.

(2) For pieces about $1\frac{7}{16}$ inches section, and for drawing temperatures around 550° C., a period of 45 minutes drawing suffices to produce the best combination of strength and ductility possible for that drawing temperature. Longer drawing results only in lowering the strength and elastic limit, without correspondingly increasing the ductility.

(3) The higher the drawing temperature is the more rapidly will the pieces come to heat.

DATA AND DISCUSSION.

METHOD AND MANIPULATION.

The stock selected for the experiment consisted of four bars of hot rolled nickel steel of the following composition:

	C.	Mn.	Si.	S.	P.	Ni.
Bar No. 1	0.46	0.48	0.095	0.037	0.035	3.19
Bar No. 2	.46					
Bar No. 3	.47					
Bar No. 4	.46					

Each bar was 8 feet long and $1\frac{7}{16}$ inches diameter. Bars No. 1 and No. 2 were used in the first part of the experiment, and bars No. 3 and No. 4 in the second part; each bar being cut into pieces $5\frac{1}{2}$ inches long for heat treatment.

Heating and cooling curves, taken on a sample of this material by the time-temperature method, showed the Ac_1 point to be at 705° C., and the Ar_1 point at 585° C. See Plate VI.

The effect of duration of drawing at two different temperatures was determined, namely, 375° C. and 550° C.

For the first series of heat treatments 24 specimens were taken from bars No. 1 and No. 2. These pieces were heated six at a time in a molten bath of sodium and calcium chlorides. The composition

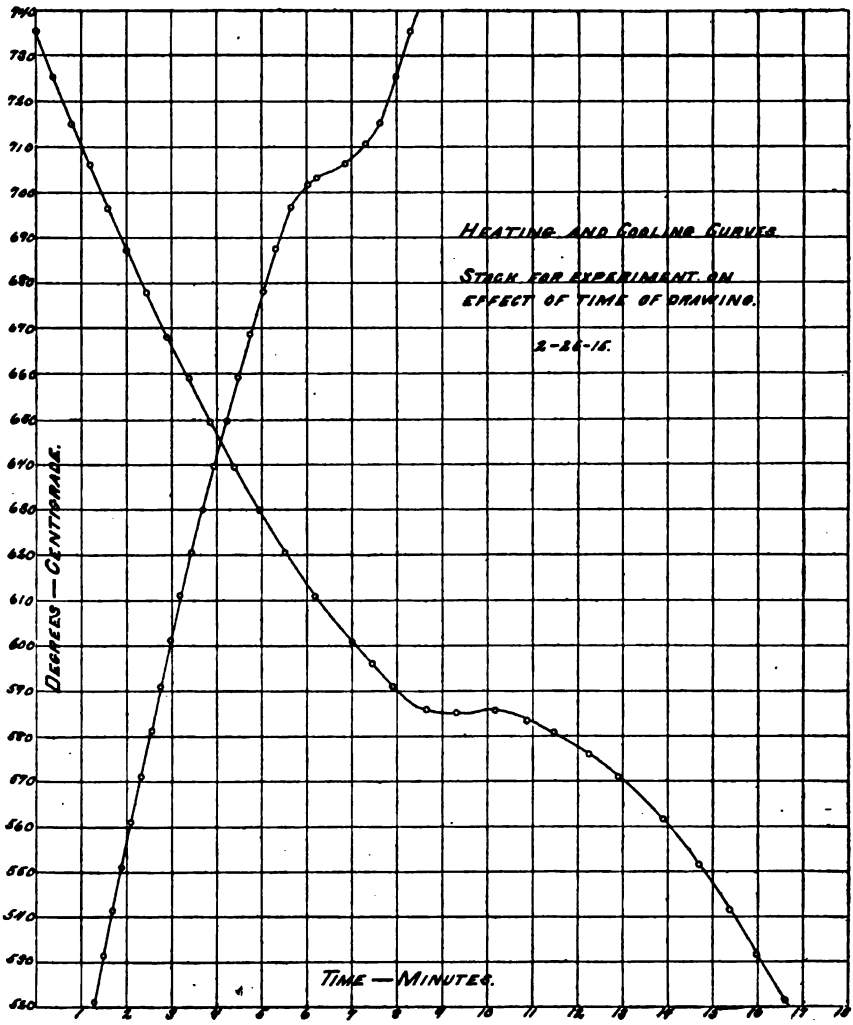


PLATE VI.

of this bath was 25 per cent of the former and 75 per cent of the latter salt. The bath was maintained at a constant temperature of 750° C. The specimens were immersed in it, and held at that temperature for 30 minutes. They were then withdrawn and quenched in whale oil.

For the second series of heat treatments 30 pieces were taken from bars No. 3 and No. 4. Since the molten salt bath was out of order,

the 30 pieces were heated at one time in the large heating furnace at the east end of the smith shop. It was decided to use 825° C. as the quenching temperature to insure quenching from above the Ac_3 point. The specimens were put into the cold furnace and heated up with it. Temperatures were measured by a base metal thermocouple in contact with the pieces. The pieces were considered to be at temperature when the couple showed 825° C., and the pieces themselves were of the same color as the thermocouple protection tube. The specimens were held at heat for 30 minutes and quenched in whale oil.

The drawing operation for both series was done in a molten bath of sodium and potassium nitrates, 50 per cent of each salt. Series No. 1 was drawn at 375° C., and series No. 2 at 550° C. The procedure, except for the difference in temperature, was the same in each case. The specimens suitably marked were placed in a wire basket. The basket containing the specimens were immersed in the molten bath and at the ends of the proper time intervals the specimens were withdrawn. Before immersing the specimens the bath was heated to 50° C. above the desired drawing temperature. The introduction of the specimens lowered the temperature to the desired point, where it was held constant throughout the drawing operation.

After heat treatment the bars were machined into tensile test specimens of 0.505-inch diameter and tested for tensile properties and hardness. They were subsequently examined for microstructure.

Table I gives complete results of the tensile and hardness tests on series No. 1, and Table II gives the average values from which the curves on Plates I and II were drawn. Table II also gives the average values of the ratio of elastic limit to maximum strength and McKenna's merit figure. This merit figure, which was put forward some years ago, is an attempt to express as a single factor the various values obtained in the tensile test. It is derived thus: $M=\frac{T(E+20)}{100000}$

where T = tensile strength and
E = per cent elongation in 2 inches

The values of this factor are given as a matter of interest.

TABLE I.—*Series No. 1. (Oil quenched at 750° C. and drawn at 375° C.)*

Marks.	Time of drawing.	Yield point (pounds per square inch).	Tensile strength (pounds per square inch).	Elongation (per cent).	Contraction of area (per cent).	Brinell hardness No.	Appearance of fracture.
A 1	Not drawn	120,000	190,000	7.5	5.7	364	Fine granular.
A 2	Not drawn						
A 3	1 min	189,500	235,500	5.5	5.7	444	Do.
A 4	do	120,000	169,000	7.5	16.9	364	Fine granular, small silky spot at circumference.
A 5	3 min	124,000	164,000	10.5	34.0	351	Silky.
A 6	do	159,000	184,500	9.5	27.4	418	Fine silky, 10 per cent; fine granular, 90 per cent.
A 7	5 min	130,000	159,000	10.0	34.0	387	Fine silky, 20 per cent; fine granular, 80 per cent.
A 8	do	143,500	168,500	12.0	34.0	351	Fine silky, 25 per cent; fine granular, 75 per cent.
A 9	10 min	144,000	173,500	11.5	34.0	375	Fine silky, 40 per cent; fine granular, 60 per cent.
A 10	do	130,000	162,000	11.0	34.0	347	Fine silky.
A 11	20 min	136,500	161,500	13.0	40.3	362	Do.
A 12	do	129,000	156,000	13.0	40.3	351	Do.

TABLE I.—*Series No. 1. (Oil quenched at 750° C. and drawn at 375° C.)*—Continued.

Marks.	Time of drawing.	Yield point (pounds per square inch).	Tensile strength (pounds per square inch).	Elongation (per cent).	Contraction of area (per cent).	Brinell hardness No.	Appearance of fracture.
A 13....	30 min.....	102,500	138,000	16.0	46.2	306	Fine silky, cup shaped.
A 14....	.....do.....	120,000	152,500	14.0	40.3	340	Fine silky.
A 15....	45 min.....	84,500	130,000	18.0	46.2	293	Do.
A 16....	.....do.....	98,000	141,000	12.0	46.2	321	Do.
B 17....	1 hr.....	76,000	122,500	20.5	57.2	262	Do.
B 18....	.....do.....	75,500	122,000	19.5	54.6	255	Fine silky, cup shaped.
B 19....	2 hrs.....	75,500	119,000	21.5	57.2	257	Do.
B 20....	.....do.....	75,500	118,000	22.0	57.2	255	Do.
B 21....	3 hrs.....	77,500	122,500	20.5	57.2	262	Fine silky.
B 22....	.....do.....	80,000	120,500	19.5	57.2	255	Do.
B 23....	4 hrs.....	76,000	119,500	21.5	57.2	255	Do.
B 24....	.....do.....	78,000	121,000	21.5	57.2	255	Do.

TABLE II.—*Series No. 1. (Average values.)*

Marks.	Time of drawing.	Yield point (pounds per square inch).	Tensile strength (pounds per square inch).	Elongation (per cent).	Contraction of area (per cent).	Brinell hardness No.	Ratio of elastic limit to maximum strength.	McKenna's merit figure.
1.....	Not drawn....	120,000	190,000	7.5	5.7	364	63.2	52.3
3, 4.....	1 min.....	159,750	202,250	6.5	11.3	404	79.0	53.6
5, 6.....	3 min.....	141,500	174,250	10.0	30.7	384	81.2	52.3
7, 8.....	5 min.....	136,750	163,750	11.0	34.0	369	83.5	50.8
9, 10.....	10 min.....	137,000	167,750	11.25	34.0	361	81.6	52.4
11, 12....	20 min.....	132,750	158,750	13.0	40.3	356	83.6	52.4
13, 14....	30 min.....	111,250	145,250	15.0	43.25	323	76.6	50.9
15, 16....	45 min.....	91,250	135,500	15.0	46.2	307	67.4	47.4
17, 18....	1 hr.....	75,750	122,250	20.0	55.9	258	62.0	48.9
19, 20....	2 hrs.....	75,500	118,500	21.75	57.2	256	63.7	49.5
21, 22....	3 hrs.....	78,750	121,500	20.0	57.2	258	64.8	48.6
23, 24....	4 hrs.....	77,000	120,250	21.5	57.2	255	64.1	49.9

Plates I and II show graphically the data contained in Table II. The curves on Plate II are the first one-fourth of the curves on Plate I, with the abscissæ scale lengthened 10 times. An examination of these curves shows that the effect of the drawing operation is the greatest during the first 10 minutes, and at the end of an hour it is practically complete—that is, continued drawing at this temperature, namely, 375° C., for longer than one hour causes very little change in physical properties from those that result from one hour's drawing.

Tables III and IV give the same results for the pieces drawn at 550° C. as Tables I and II give for the specimens drawn at 375° C. Plates III and IV show graphically the average values of Table IV. Plate III shows the progressive effect of drawing at 550° C. for 10 hours, while Plate IV represents only the progressive effect of drawing for one hour. The scale of abscissæ is 10 times as large on Plate IV as on Plate III.

The same general shape of the curves holds for drawing at 550° C. as for drawing at 375° C. The greatest change in properties takes place during the first 10 minutes of the drawing, while the change is nearly completed after 45 minutes' drawing. The maximum ductility is reached after drawing for 45 minutes, though there is a slow progressive falling off of strength and elastic limit even up to 10 hours.

PLATE I

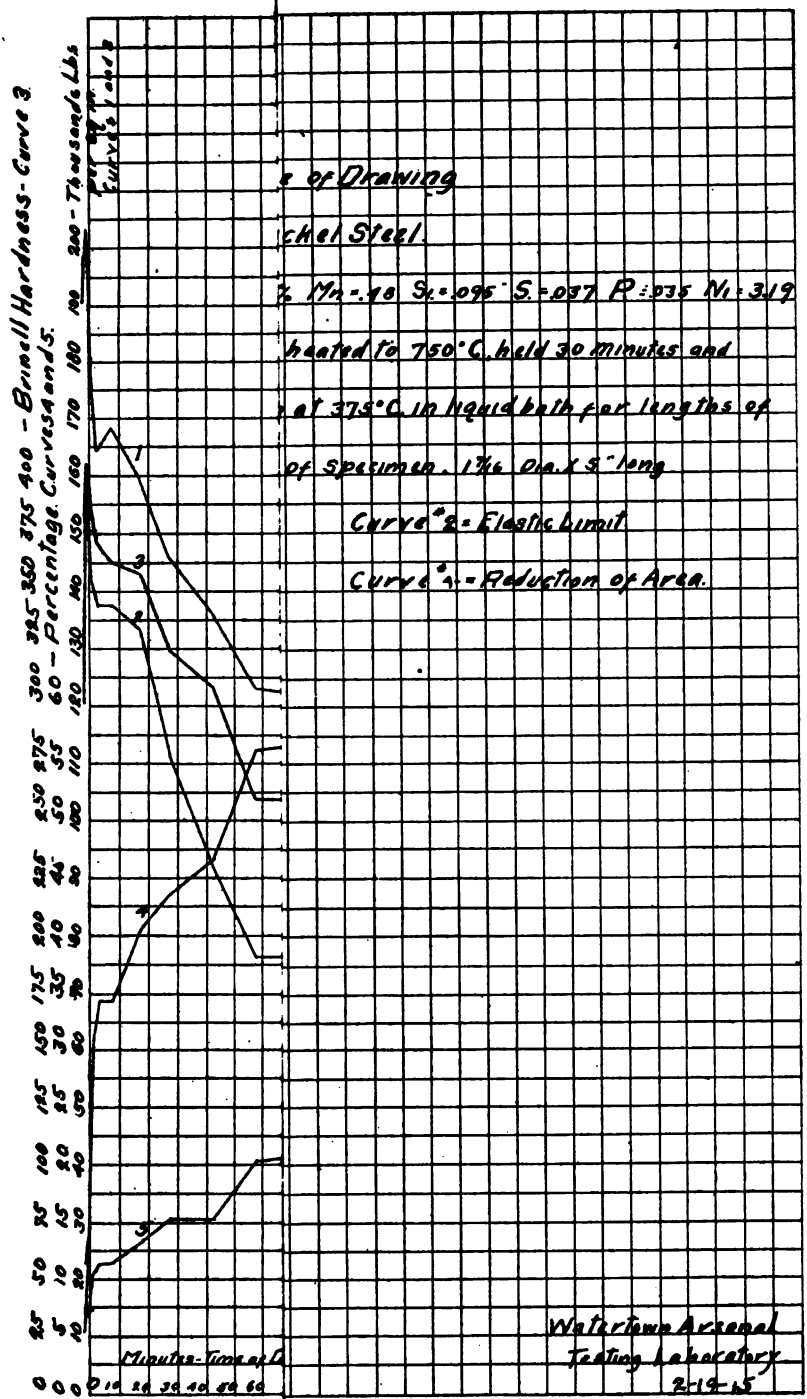
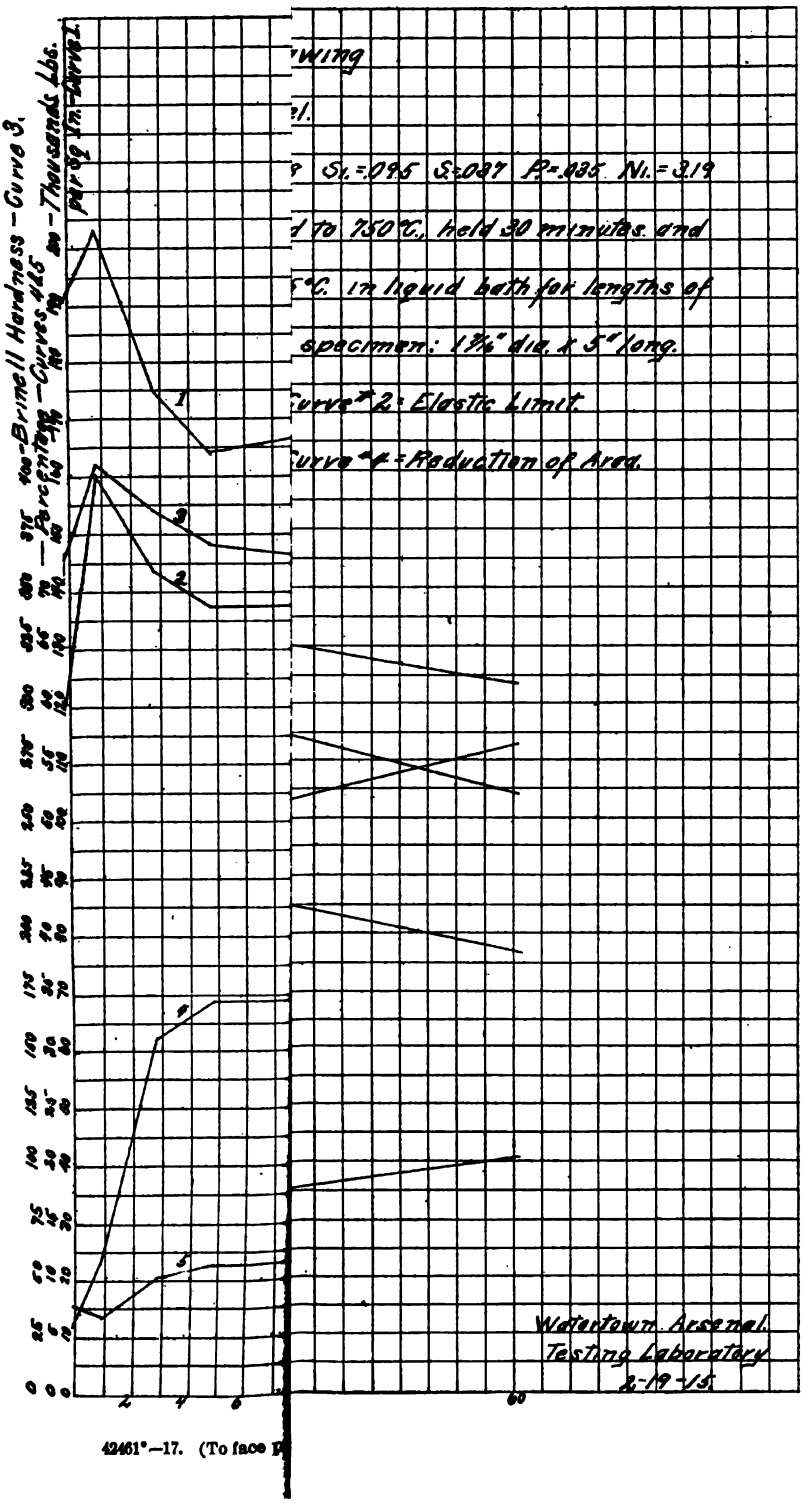
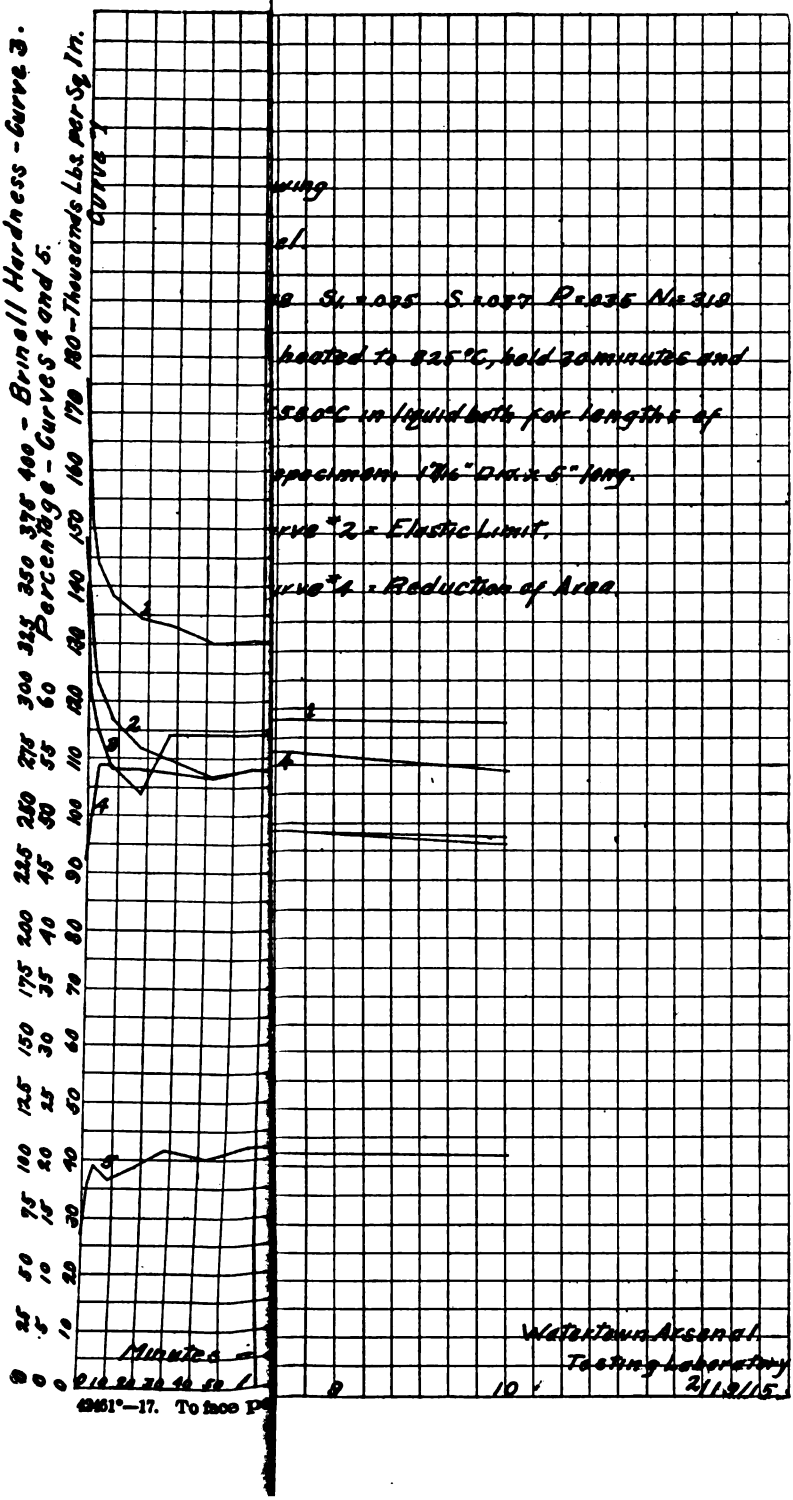

Curve 1 = 2 of Drawing
Chel Steel
% Mn = .48 Si = .095 S. = .037 P = .035 Ni = 3.19
heated to 750° C. held 30 minutes and
at 375° C. in liquid bath for lengths of
of Specimen. 1/16 Dia. x 5" long
Curve "2 = Elastic limit
Curve "4 = Reduction of Area.
Brinell Hardness - Curve 3
Percentage. Curves 4 and 5.
Thousands Lbs
Minutes - Time at
Watertown Arsenal
Testing Laboratory
2-19-15

PLATE II



42461°—17. (To face P



...ung

...el.

...18 Su = .095 S. .1037 R = .036 N = 318

heated to 825°C, held 30 minutes and

580°C in liquid bath for lengths of

specimen 1/16" Dia. x 6" long.

Curve "2 = Elastic Limit,

Curve "4 = Reduction of Area.

4961°—17. To face p...

PLATE IV

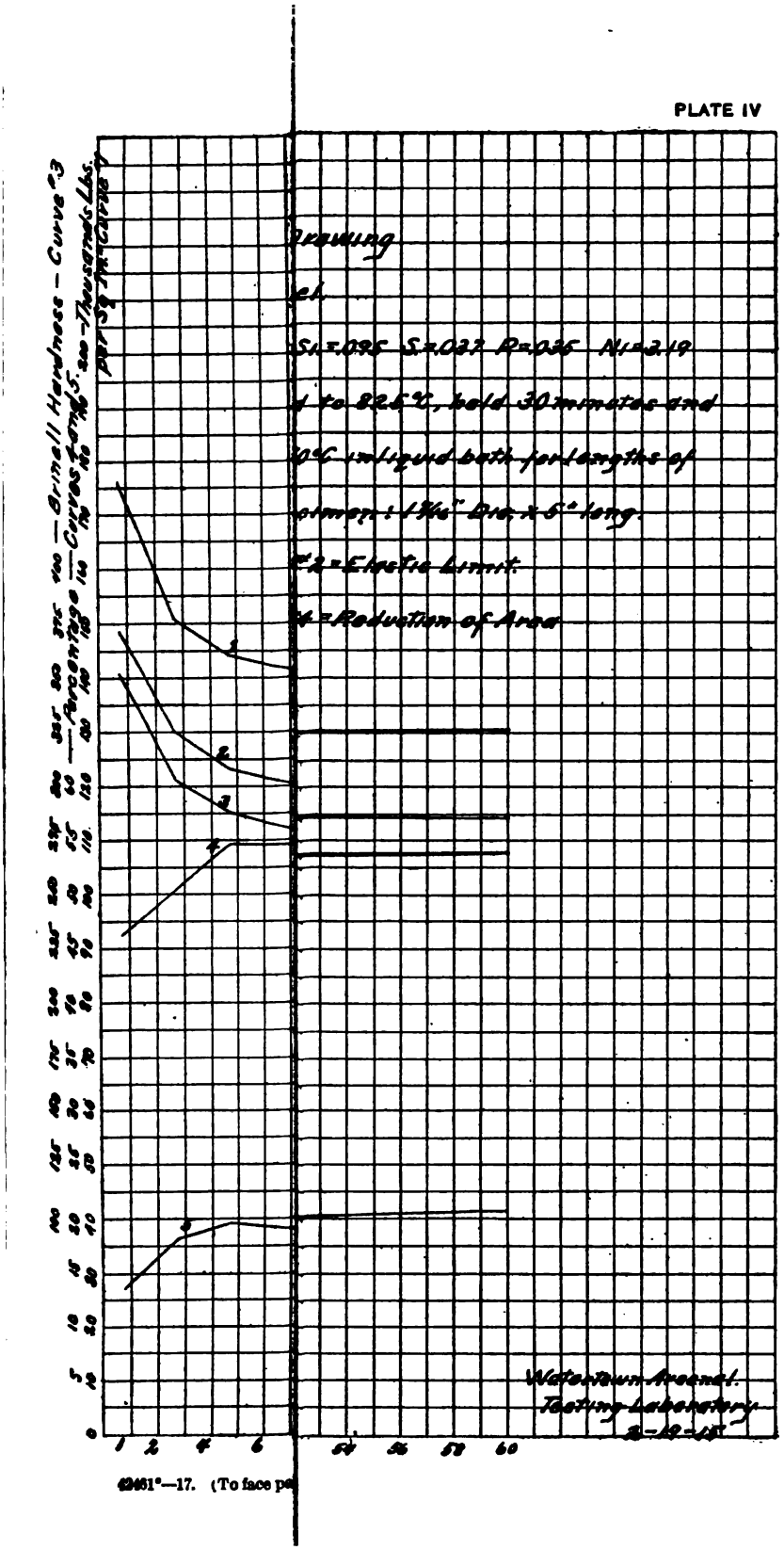

Drawing
#1.
S1=.095 S=.022 R=.026 N=2.19
4 to 822°C, held 30 minutes and
10°C in liquid both for lengths of
stock: 1 1/16" Dia. x 6" long.
E2=Elastic Limit.
R=Reduction of Area
Watertown Arsenal
Testing Laboratory
Brinell Hardness - Curve #3
Percentage Elongation in 2"
Percentage Reduction of Area
Tensile Strength
Elastic Limit
1
2
3
4
5
6
42461°—17. (To face pa

TABLE III.—*Series No. 2. (Oil quenched at 825° C. and drawn at 550° C.)*

Marks.	Time of drawing.	Yield point (pounds per square inch).	Tensile strength (pounds per square inch).	Elongation (per cent).	Contraction of area (per cent).	Brinell hardness No.	Appearance of fracture.
C 3...	1 min.....	149,000	177,000	13.5	46.2	348	Fine silky, cup shaped.
C 4...	.....do.....	148,500	176,000	13.5	46.2	357	Do.
C 5...	3 min.....	130,000	150,000	17.5	51.9	302	Do.
C 6...	.....do.....	130,000	152,000	18.5	49.1	305	Do.
C 7...	5 min.....	123,500	143,500	19.5	54.6	286	Fine silky, serrated.
C 8...	.....do.....	123,000	145,000	19.5	54.6	291	Do.
C 9...	10 min.....	118,500	139,000	18.5	57.2	286	Do.
C 10..	.....do.....	115,500	138,000	18.0	51.9	257	Do.
C 11..	20 min.....	111,500	134,500	19.0	51.9	274	Do.
C 12..	.....do.....	112,500	135,000	19.5	51.9	269	Do.
C 13..	30 min.....	109,500	132,000	21.0	57.2	269	Do.
C 14..	.....do.....	110,500	135,000	20.5	57.2	269	Do.
C 15..	45 min.....	107,500	130,000	20.5	57.2	265	Do.
C 16..	.....do.....	107,500	130,500	19.5	57.2	269	Do.
D 17..	1 hr.....	108,500	131,000	21.5	57.2	269	Do.
D 18..	.....do.....	108,000	130,500	20.5	57.2	272	Do.
D 19..	2 hrs.....	105,000	126,500	20.5	57.2	264	Do.
D 20..	.....do.....	105,000	127,000	20.5	57.2	267	Do.
D 21..	3 hrs.....	103,500	124,500	21.5	59.8	262	Do.
D 22..	.....do.....	102,500	124,000	22.0	59.8	262	Do.
D 23 .	4 hrs.....	101,000	121,500	20.5	54.6	255	Do.
D 24..	.....do.....	100,000	121,000	22.5	62.3	255	Do.
D 25..	6 hrs.....	99,500	119,500	21.0	57.2	253	Do.
D 26..	.....do.....	99,000	119,500	22.5	62.3	253	Do.
D 27..	8 hrs.....	99,500	118,500	21.0	57.2	251	Do.
D 28..	.....do.....	99,000	119,000	22.0	57.2	248	Do.
D 29..	10 hrs.....	98,000	117,500	21.0	54.6	241	Do.
D 30..	.....do.....	97,500	117,500	21.0	54.6	241	Do.

TABLE IV.—*Series No. 2. (Average of values.)*

Marks.	Time of drawing.	Yield point (pounds per square inch).	Tensile strength (pounds per square inch).	Elongation (per cent).	Contraction of area (per cent).	Brinell hardness No.	Ratio elastic limit to maximum strength.	McKenna's merit figure.
3,4.....	1 min.....	148,750	176,500	13.5	46.2	352	84.2	59.1
5,6.....	3 min.....	130,000	151,000	18.0	50.5	303	86.1	57.4
7,8.....	5 min.....	123,250	141,250	19.5	54.6	288	85.4	57.0
9,10.....	10 min.....	117,000	138,500	18.25	54.5	271	84.5	53.0
11,12....	20 min.....	112,000	134,750	19.25	51.9	271	83 2	52.9
13,14....	30 min.....	110,000	133,500	20.75	57.2	269	82.4	54.4
15,16....	45 min.....	107,500	130,250	20.0	57.2	267	82.5	52 2
17,18....	1 hr.....	108,250	130,750	21.0	57.2	270	82.8	53 6
19,20....	2 hrs.....	105,000	126,750	20.5	57.2	265	82.9	51.4
21,22....	3 hrs.....	103,000	124,250	21.75	59.8	262	82.9	51.9
23,24....	4 hrs.....	100,500	121,250	21.50	58.4	255	82.9	50.4
25,26....	6 hrs.....	99,250	119,500	21.75	59.8	253	83.0	49.9
27,28....	8 hrs.....	99,250	118,750	21.50	57.2	250	83.5	49.3
29,30....	10 hrs.....	97,750	117,500	21.0	54.6	241	83.2	48.2

APPENDIX I.

MICROEXAMINATION OF SPECIMENS.

Selected specimens from each series were taken for microscopic examination. From series No. 1, specimens A 1, A 3, A 4, A 5, A 6, A 8, A 9, A 11, A 13, A 14, A 15, A 16, A 17, A 19, A 21, and A 24 were examined, while from series No. 2 all even numbered specimens were examined.

In the first series the structure of the first specimen consisted of very fine martensite with islands of troostite, and a very little ferrite.

As this specimen was not drawn, the small amount of troostite was evidently formed during the quenching operation. As the time of drawing increases with these specimens, the amount of ferrite increases somewhat, and the amount of troostite increases very markedly with a progressive disappearance of the martensite. The micrographs appended will illustrate the appearance of the structure.

Micrograph No. 1, specimen A 3, drawn for 1 minute, shows fine-grained martensite and black patches of troostite. The ferrite patches are scarcely visible. This is taken at 75 diameters.

Micrograph No. 2 shows the same at 400 diameters.

Micrographs No. 3 and No. 4 show specimen No. A 5 drawn for 3 minutes, at 75 and 400 diameters, respectively. The troostite is more abundant and the ferrite more readily visible. Micrograph No. 5 shows specimen No. A 14 drawn 30 minutes, magnified 75 diameters. The martensite has disappeared almost entirely, and the structure is troostite with patches of ferrite. Micrograph No. 6 shows specimen No. B 19 drawn 2 hours, magnified 75 diameters. The structure is sorbito-troostite with the ferrite tending to form a network. This structure is characteristic of the specimens drawn at 2, 3, and 4 hours at this temperature.

In the second series the martensite formed by quenching was somewhat coarser because of the higher quenching temperatures. The following micrographs will illustrate the structure.

Micrograph No. 7 shows specimen C 6 drawn for 3 minutes, magnified 75 diameters. The picture is dark on one side, due to a lighting effect. The structure is medium fine martensite with patches of troostite and ferrite.

Micrograph No. 8.—Specimen C 6 at 400 diameters. This picture shows the structure better than the previous one at 75 diameters.

Micrographs No. 9 and No. 10.—Specimen C 16, drawn for 45 minutes. Magnified 75 and 400 diameters, respectively. This structure consists of very nearly uniform sorbite.

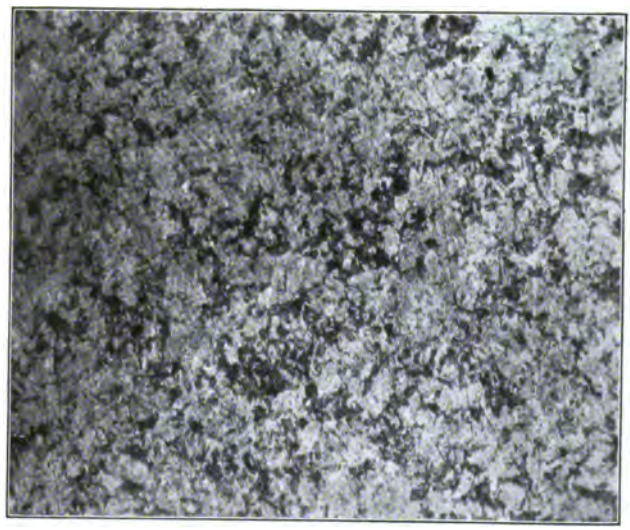
Micrographs No. 11 and No. 12.—Specimen C 30, drawn for 10 hours. Magnified 75 and 400 diameters, respectively. The dark corner on No. 11 is lighting effect. The structures are sorbite with more or less coalesced ferrite. This structure is characteristic of the specimens drawn at 550° C. for 4 to 10 hours.

APPENDIX II.

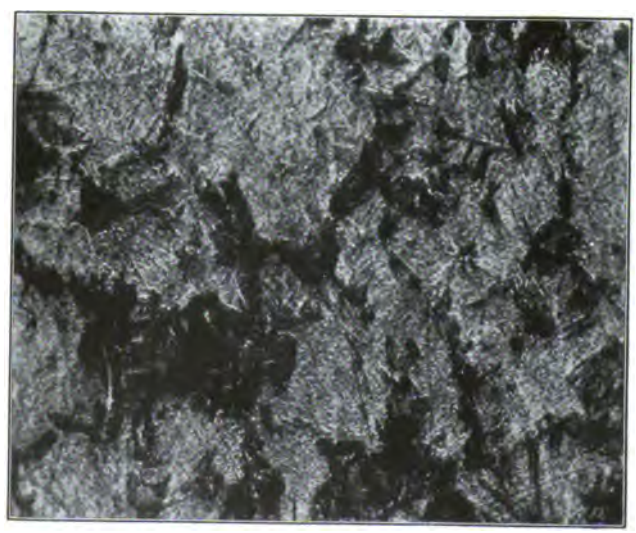
RATE OF PENETRATION OF HEAT.

In order to determine the length of time required for the specimens to come to the temperature of the drawing bath, the following auxiliary experiment was performed.

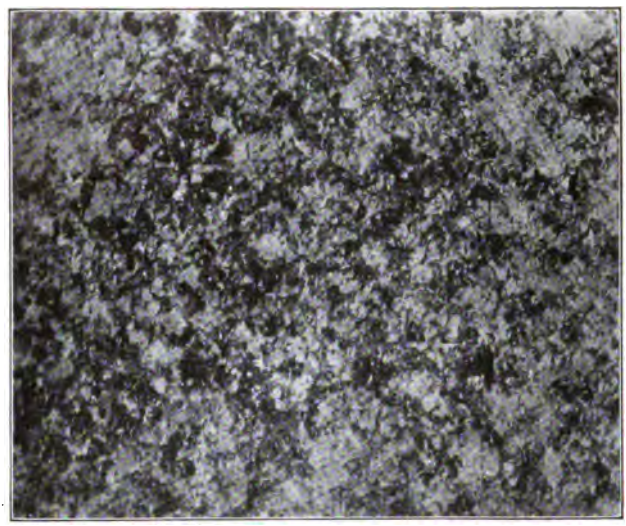
A specimen $5\frac{1}{2}$ inches long by $1\frac{7}{16}$ inches diameter of the same nickel steel was drilled along the axis with an $\frac{1}{8}$-inch drill to within 1 inch of the bottom. A rare metal thermocouple was inserted in the hole and the specimen immersed within a quarter of an inch of the top in the drawing bath. Time and temperature readings were taken until the thermocouple in the specimen recorded the temperature of the bath. The appended curves show graphically the results obtained. It will be noted that the specimen takes longer to come to the lower temperature than to the higher. (See Plate V.)



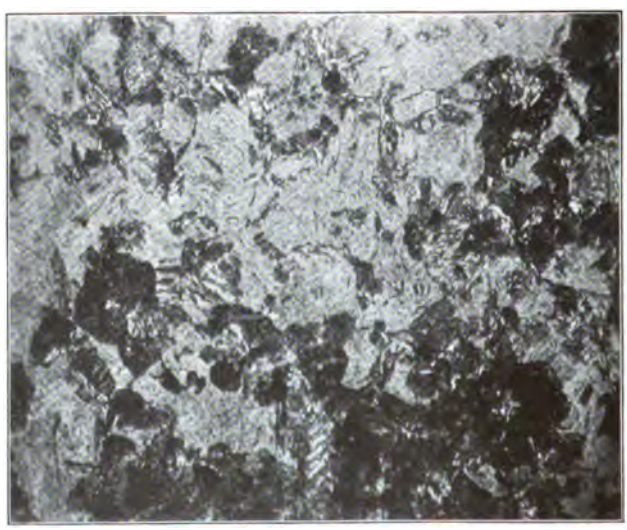
PHOTOGRAPH NO. 1. A3. (X75.)
Drawn one minute at 375° C.



PHOTOGRAPH NO. 2. A3. (X400.)
Drawn one minute at 375° C.

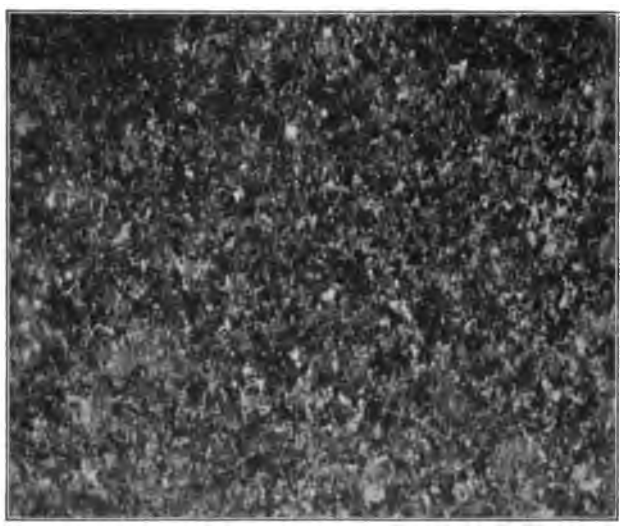


PHOTOGRAPH NO. 3. A5. (X75.)
Drawn three minutes at 375° C.

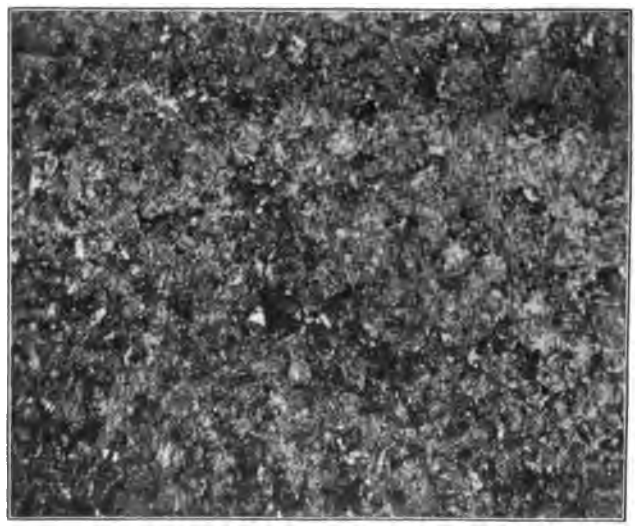


PHOTOGRAPH NO. 4. A5. (X400.)
Drawn three minutes at 375° C.

PHOTOGRAPH NO. 5. A14. (X75.)
Drawn 30 minutes at 375° C.



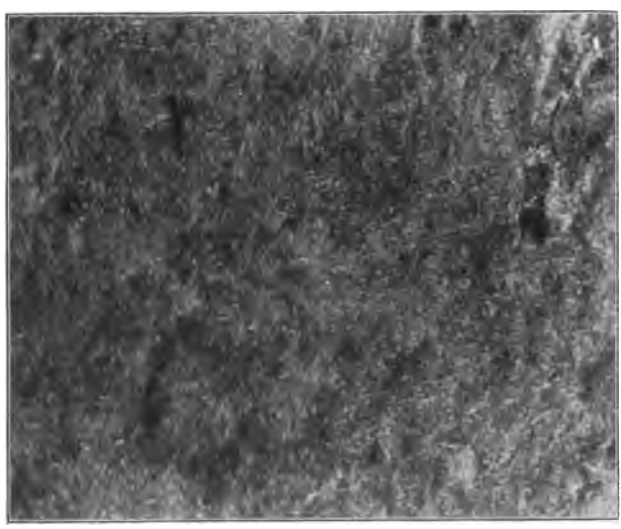
PHOTOGRAPH NO. 6. A19. (X75.)
Drawn two hours at 375° C.



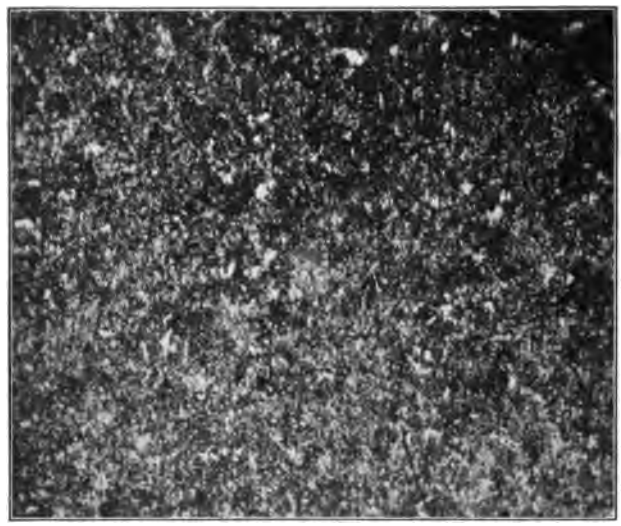
PHOTOGRAPH NO. 7. C6. (×75.)
Drawn three minutes at 550° C.

PHOTOGRAPH NO. 8. C6. (×400.)
Drawn three minutes at 550° C.

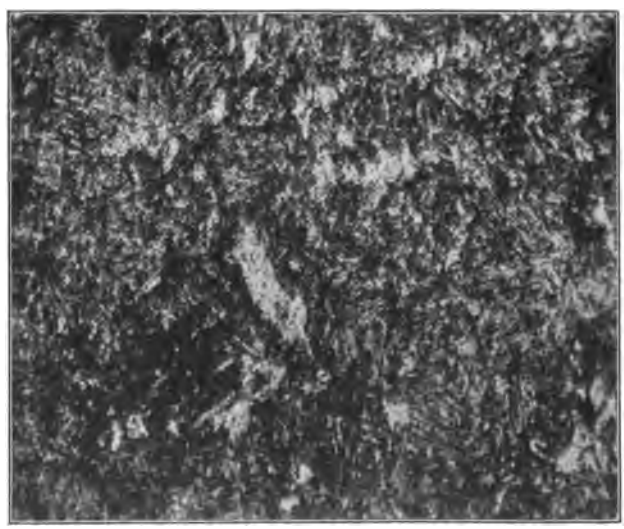
PHOTOGRAPH NO. 9. C16. (X75.)
Drawn 45 minutes at 550° C.



PHOTOGRAPH NO. 10. C16. (X400.)
Drawn 45 minutes at 550° C.

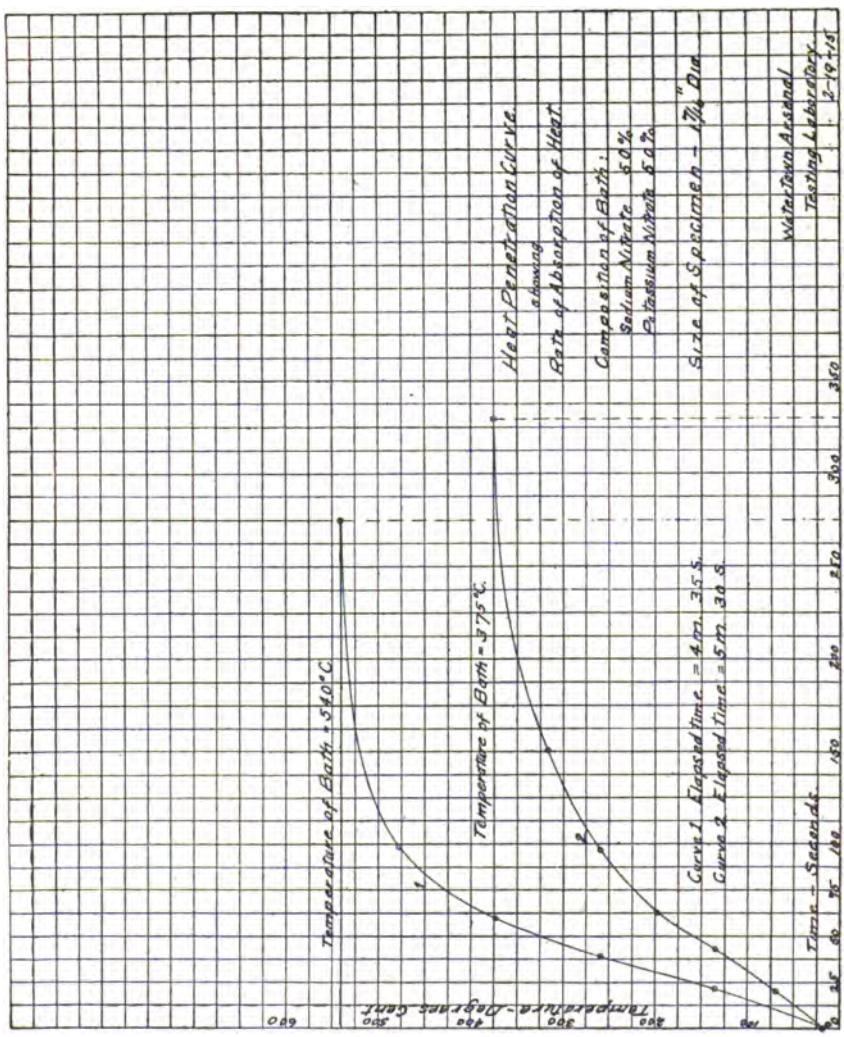


PHOTOGRAPH NO. 11. C20. (×75.)
Drawn 10 hours at 550° C.



PHOTOGRAPH NO. 12. C30. (×400.)
Drawn 10 hours at 550° C.

Plate V.


Heat Penetration Curve
showing
Rate of Absorption of Heat
Composition of Bath:
Sodium Nitrate 50%
Potassium Nitrate 50%
Size of Specimen – 1/2" Dia
Watertown Arsenal
Testing Laboratory
3-19-15
Temperature of Bath = 340°C
Temperature of Bath = 375°C
Curve 1 Elapsed time = 4m. 35 S.
Curve 2 Elapsed time = 5m. 30 S.
Time – Seconds
Temperature – Degrees Cent.

THE EFFECT OF RATE OF COOLING AFTER DRAWING ON THE RESISTANCE TO SHOCK AS REGISTERED BY THE CHARPY IMPACT TEST.

INTRODUCTION.

It is widely accepted that the physical properties of hardened and drawn steel are independent of the rate of cooling from the drawing temperature. This belief has been expressed by Sauveur [1] in the following words:

> Once the desired amount of tempering is effected, * * * the rate of cooling to atmospheric temperature appears to be quite immaterial. * * * The theory is that while by keeping the metal at a certain temperature its tempering may be carried further, on cooling the tempering ceases, * * * so that the rate of cooling is without influence.

This is, of course, perfectly in line with the theoretical conceptions of the constitution of steel, since no critical points exist within the range of drawing temperatures. Hence no change in the constitution of steel could be affected by the rate of cooling. It has appeared possible, however, that by rapid cooling from drawing temperatures with accompanying unequal contractions in the metal, internal stresses might be set up which persist at atmospheric temperatures, and so affect the steel to its detriment. It has also seemed probable that if such stresses did exist in steel they would affect its resistance to shock more markedly than any other property. With a view, then, to investigating this question, the experiment reported herein was carried out. The practical application of any data on this subject is evident. If such stresses as described are set up, if the resistance to shock is materially reduced by rapid cooling after drawing, then such methods of rapid cooling should be avoided, especially for material which is to be subject to dynamic stress.

DESCRIPTION OF MATERIAL AND METHODS.

The general plan for carrying out this investigation was as follows: Twenty-four similar pieces of a hypoeutectoid steel, all of which should be in the same physical condition and each large enough to cut into six Charpy test specimens, were to be quenched in water from 25° above the Ar_3 point. These 24 pieces of hardened steel were to be drawn as follows:

		Mark.
Draw 3 at 300° C.	Cool one in furnace	S 3 F
	Cool one in air	S 3 A
	Cool one in water	S 3 W
Draw 3 at 400° C.	Cool one in furnace	S 4 F
	Cool one in air	S 4 A
	Cool one in water	S 4 W

[1] The Metallography of Iron & Steel. Lesson XIV, pp. 2.

		Mark.
Draw 3 at 500° C.	Cool one in furnace	S 5 F
	Cool one in air	S 5 A
	Cool one in water	S 5 W
Draw 3 at 600° C.	Cool one in furnace	S 6 F
	Cool one in air	S 6 A
	Cool one in water	S 6 W
Draw 3 at 650° C.	Cool one in furnace	S 65 F
	Cool one in air	S 65 A
	Cool one in water	S 65 W
Draw 3 at 675° C.	Cool one in furnace	S 67 F
	Cool one in air	S 67 A
	Cool one in water	S 67 W
Draw 3 at 700° C.	Cool one in furnace	S 7 F
	Cool one in air	S 7 A
	Cool one in water	S 7 W
Draw 3 at 725° C.	Cool one in furnace	S C F
	Cool one in air	S C A
	Cool one in water	S C W

After heat treatment, transverse Charpy impact specimens were to be prepared and tested and conclusions drawn.

The material selected was a bar of hot rolled mild machinery steel $\frac{5}{8}$ inch by $3\frac{1}{2}$ inches. Twenty-four pieces, each 3 inches long, were cut from this bar. The chemical composition by analysis was as follows:

	Per cent.
Carbon	0.20
Manganese	.40
Silicon	.032
Sulphur	.033
Phosphorus	.012

Microscopic examination showed the material to consist of fairly fine-grained ferrite and lamellar pearlite. The structure is shown in micrograph No. 1, which is a cross-section taken at 75 diameters.

A mild steel was selected because from previous experience it was known that a properly treated mild steel would possess greater resistance to shock than a hard steel. Likewise, since the cooling from the drawing temperature was not to influence the carbon condition, it seemed that the actual percentage of carbon in the steel was an inconsequential factor.

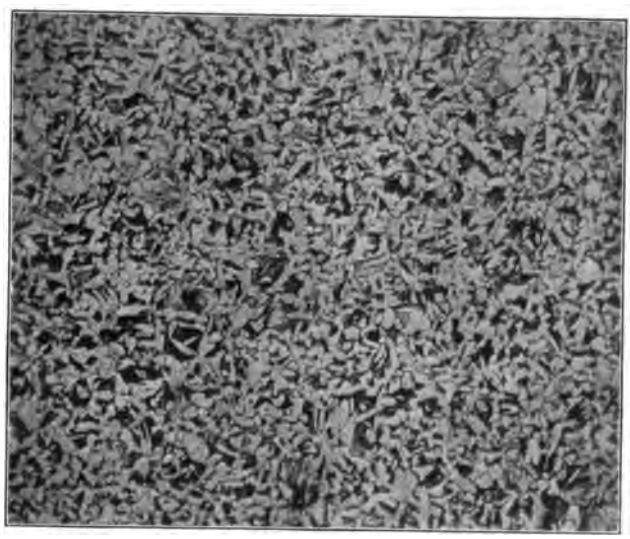
All heating operations were carried out in the laboratory in small closed muffle electrically heated furnaces, in which the heat distribution is very uniform. The temperatures were measured with previously calibrated platinum-platinum rhodium thermocouples in conjunction with a Leeds & Northrup precision potentiometer. For the hardening operation the pieces were heated six at a time. They were brought up gradually with the furnace to 900° C., and then allowed to cool slowly to 825° C. At this temperature they were taken out and quenched individually in cold water. About two and a half hours elapsed from the time of starting till the pieces were quenched. The drawing operations were carried out in the same muffle furnaces, three pieces being heated at a time. They were put in the cold furnace, brought up to the desired heat, held at that temperature one-half hour and cooled in furnace air and water, as indicated in the program.

Standard tranverse Charpy impact specimens were machined from the heat-treated pieces. These were tested on the laboratory Charpy

impact machine of 30 kilogrammeter capacity. The results are shown in the following tables.

TABLE 1.—*All observed results.*

Mark.	Sectional area (square inches).	Charpy test results.		Brinell hardness No.	Character of fracture.
		Foot-pounds absorbed.	Foot-pounds per square inch.		
S 3 F 1	0.0776	32.6	420.0	160	½ crystalline.
S 3 F 2	.0780	49.3	631.5	160	Fibrous.
S 3 F 3	.0780	32.6	418.0	204	½ crystalline.
S 3 F 4	.0776	44.1	568.0	176	Fibrous.
S 3 F 5	.0780	47.5	609.0	160	Do.
S 3 F 6	.0780	42.4	543.0	162	Do.
S 3 A 1	.0782	28.0	358.0	228	½ crystalline.
S 3 A 2	.0782	33.4	427.0	208	½ crystalline.
S 3 A 3	.0776	39.05	503.0	192	Fibrous and crystalline.
S 3 A 4	.0780	44.1	565.0	200	Do.
S 3 A 5	.0780	32.6	418.0	180	½ crystalline.
S 3 A 6	.0780	47.5	609.0	192	Fibrous.
S 3 W 1	.0775	25.0	326.0	268	Crystalline.
S 3 W 2	.0776	44.1	568.0	172	Fibrous.
S 3 W 3	.0780	40.7	521.5	252	Fibrous and crystalline.
S 3 W 4	.0776	33.4	430.0	184	½ crystalline.
S 3 W 5	.0776	30.25	390.0	176	½ crystalline.
S 3 W 6	.0776	37.40	481.5	192	Fibrous and crystalline.
S 4 F 1	.0776	32.6	420.0	216	½ crystalline.
S 4 F 2	.0776	43.2	556.0	156	Fibrous and crystalline.
S 4 F 3	.0776	31.05	400.0	180	½ crystalline.
S 4 F 4	.0775	37.40	483.0	196	Fibrous and crystalline.
S 4 F 5	.0780	44.95	576.0	160	Fibrous.
S 4 F 6	.0780	49.3	632.0	192	Do.
S 4 A 1	.0780	46.65	598.0	180	Do.
S 4 A 2	.0780	30.25	388.0	200	½ crystalline.
S 4 A 3	.0780	38.2	490.0	200	½ crystalline.
S 4 A 4	.0776	45.8	590.0	176	Fibrous.
S 4 A 5	.0780	47.5	609.0	184	Do.
S 4 A 6	.0780	39.85	511.0	216	½ crystalline.
S 4 W 1	.0780	29.50	378.0	228	½ crystalline.
S 4 W 2	.0780	28.75	368.0	200	½ crystalline.
S 4 W 3	.0776	28.75	370.0	228	½ crystalline.
S 4 W 4	.0776	28.75	370.0	268	½ crystalline.
S 4 W 5	.0780	35.80	459.0	244	½ crystalline.
S 4 W 6	.0780	34.20	438.0	180	Fibrous.
S 5 F 1	.0780	41.55	532.5	180	Fibrous and crystalline.
S 5 F 2	.0776	28.0	360.5	184	½ crystalline.
S 5 F 3	.0780	31.8	407.5	200	½ crystalline.
S 5 F 4	.07785	46.65	600.0	156	Fibrous.
S 5 F 5	.0782	36.60	468.0	152	Fibrous and crystalline.
S 5 F 6	.0780	44.1	565.0	156	Fibrous.
S 5 A 1	.0782	31.05	397.0	200	½ crystalline.
S 5 A 2	.0780	35.80	459.0	176	Fibrous and crystalline.
S 5 A 3	.0786	35.80	455.0	180	Do.
S 5 A 4	.0782	38.2	388.5	180	Do.
S 5 A 5	.07785	44.1	566.0	180	Fibrous.
S 5 A 6	.0776	26.5	341.0	184	½ crystalline.
S 5 W 1	.0780	35.0	449.0	180	Fibrous and crystalline.
S 5 W 2	.0776	28.0	360.5	216	½ crystalline.
S 5 W 3	.0776	43.2	556.0	148	Fibrous.
S 5 W 4	.0776	.....	.....	160	Fibrous and crystalline.
S 5 W 5	.0780	44.95	576.0	152	Fibrous.
S 5 W 6	.0784	31.05	396.0	208	½ crystalline.
S 6 F 1	.0782	39.85	510.0	156	Fibrous and crystalline.
S 6 F 2	.0780	28.75	368.0	160	Do.
S 6 F 3	.0780	50.15	643.5	160	Fibrous.
S 6 F 4	.0776	27.25	351.0	156	½ crystalline.
S 6 F 5	.0776	45.8	590.0	144	Fibrous.
S 6 F 6	.0776	48.4	623.5	152	Do.
S 6 A 1	.0780	47.5	609.0	132	Do.
S 6 A 2	.0780	51.95	666.0	128	Do.
S 6 A 3	.0775	29.50	381.0	152	½ crystalline.
S 6 A 4	.0776	28.0	360.5	176	Do.
S 6 A 5	.0780	46.65	598.0	142	Fibrous.
S 6 A 6	.0778	49.3	634.0	140	Do.
S 6 W 1	.0776	33.4	430.0	164	½ crystalline.
S 6 W 2	.0776	56.4	726.0	148	Fibrous.
S 6 W 3	.0780	34.2	439.0	172	½ crystalline.
S 6 W 4	.0775	32.6	421.0	172	Do.
S 6 W 5	.0778	39.05	502.0	160	½ crystalline.



MICRO NO. 1. (×75.)

TABLE 1.—*All observed results*—Continued.

Mark.	Sectional area (square inches).	Charpy test results.		Brinell hardness No.	Character of fracture.
		Foot-pounds absorbed.	Foot-pounds per square inch.		
S 6 W 6	0.0776	20.80	268.0	172	Crystalline.
S 65 F 1	.0782	31.8	406.5	155	Fibrous and crystalline.
S 65 F 2	.07785	34.2	440.0	148	¼ crystalline.
S 65 F 3	.0782	56.4	721.5	140	Fibrous.
S 65 F 4	.07785	51.05	656.0	144	Do.
S 65 F 5	.0778	59.15	760.0	136	Do.
S 65 F 6	.0780	51.05	655.0	136	Do.
S 65 A 1	.0780	47.50	609.0	132	Do.
S 65 A 2	.07785	51.05	656.0	138	Do.
S 65 A 3	.0782	26.50	339.0	156	¾ crystalline.
S 65 A 4	.0778	52.85	680.0	152	Fibrous.
S 65 A 5	.0782	40.70	520.0	152	Fibrous and crystalline.
S 65 A 6	.0776	31.05	400.0	140	¼ fibrous.
S 65 W 1	.0780	46.65	598.0	160	Fibrous and crystalline.
S 65 W 2	.0776	35.0	451.0	148	Do.
S 65 W 3	.0776	28.75	370.0	164	¾ crystalline.
S 65 W 4	.0776	51.05	658.0	156	Fibrous.
S 65 W 5	.0776	30.25	390.0	.....	Fibrous and crystalline.
S 65 W 6	.0776	28.0	360.5	172	¾ crystalline.
S 67 F 1	.0780	32.6	418.0	148	Do.
S 67 F 2	.0776	31.8	410.0	148	¼ crystalline.
S 67 F 3	.0776	56.4	726.6	130.5	Fibrous.
S 67 F 4	.0776	47.50	611.5	144	Do.
S 67 F 5	.0776	44.1	568.0	134.5	Fibrous and crystalline.
S 67 F 6	.0782	51.05	653.0	138	Fibrous.
S 67 A 1	.0780	46.65	598.0	152	Fibrous and crystalline.
S 67 A 2	.07785	47.50	610.0	144	Fibrous.
S 67 A 3	.0776	32.6	420.0	164	¾ crystalline.
S 67 A 4	.0776	28.0	360.5	160	Do.
S 67 A 5	.0780	52.85	678.0	152	Fibrous.
S 67 A 6	.0780	49.3	632.0	152	Do.
S 67 W 1	.0776	30.25	390.0	156	¾ crystalline.
S 67 W 2	.0776	41.55	535.0	140	Fibrous and crystalline.
S 67 W 3	.0780	44.1	565.0	144	Do.
S 67 W 4	.0780	37.40	480.0	144	¼ crystalline.
S 67 W 5	.0780	35.0	449.0	152	Do.
S 67 W 6	.0780	52.85	678.0	140	Fibrous.
S 7 F 1	.07785	35.80	460.0	140	¼ crystalline.
S 7 F 2	.07785	60.10	772.0	116.5	Fibrous.
S 7 F 3	.0776	39.05	503.0	138	Fibrous and crystalline.
S 7 F 4	.0776	35.80	461.0	138	¼ crystalline.
S 7 F 5	.0782	61.00	780.0	125	Fibrous.
S 7 F 6	.0776	51.05	658.0	119	Fibrous and crystalline.
S 7 A 1	.07785	43.2	555.0	125	Do.
S 7 A 2	.07785	51.95	668.0	138	Fibrous.
S 7 A 3	.07785	47.50	610.0	130.5	Fibrous and crystalline.
S 7 A 4	.0776	26.50	341.5	148	¾ crystalline.
S 7 A 5	.0776	52.85	680.0	130.5	Fibrous.
S 7 A 6	.0776	42.4	546.0	125	Fibrous and rystalline.
S 7 W 1	.0780	23.6	303.0	140	Crystalline.
S 7 W 2	.0776	25.75	332.0	152	¾ crystalline.
S 7 W 3	.0773	35.0	453.0	140	Fibrous and crystalline.
S 7 W 4	.0776	45.8	590.0	148	Do.
S 7 W 5	.0775	44.95	580.0	140	Do.
S 7 W 6	.0776	50.15	646.0	138	Fibrous.
S C F 1	.0776	22.15	285.5	117	¼ crystalline.
S C F 2	.0776	21.45	276.0	109	Crystalline.
S C F 3	.07785	20.10	258.0	119	Do.
S C F 4	.0782	25.0	320.0	109	Fibrous and crystalline.
S C F 5	.0782	25.75	329.0	111	Do.
S C F 6	.0780	25.75	330.0	110	Crystalline.
S C A 1	.0780	25.0	320.5	119	¾ crystalline.
S C A 2	.0780	25.0	320.5	125	¼ crystalline.
S C A 3	.0780	25.0	320.5	116	¾ crystalline.
S C A 4	.0780	24.3	312.0	119	Do.
S C A 5	.0776	37.40	481.5	114	Fibrous and crystalline.
S C A 6	.0780	31.05	398.0	116	¼ crystalline.
S C W 1	.0780	31.05	398.0	156	Fibrous and crystalline.
S C W 2	.0775	42.4	547.0	172	Fibrous.
S C W 3	.0776	37.4	481.5	164	Fibrous and crystalline.
S C W 4	.0776	36.6	471.5	160	Do.
S C W 5	.0780	42.4	544.0	152	Fibrous.
S C W 6	.0780	33.4	428.0	180	Fibrous and crystalline.

TABLE 2.—*Mean values.*

Mark.	Charpy results (foot-pounds per square inch).			Percentage lower than furnace cooled.	Brinell hardness No.	Method of drawing.
	Maximum.	Minimum.	Average.			
				Per cent.		
S 3 F	631.5	418.0	531.6	0	170.3	Furnace cooled from 300° C.
S 3 A	609.0	358.0	536.6	[1] 1.9	200.0	Air cooled from 300° C.
S 3 W	568.0	323.0	452.3	14.9	207.3	Water cooled from 300° C.
S 4 F	632.0	400.0	511.2	0	183.3	Furnace cooled from 400° C.
S 4 A	609.0	388.0	531.0	[1] 3.9	192.7	Air cooled from 400° C.
S 4 W	459.0	370.0	397.2	22.3	224.7	Water cooled from 400° C.
S 5 F	600.0	360.5	488.9	0	171.3	Furnace cooled from 500° C.
S 5 A	566.0	341.0	434.4	11.1	183.3	Air cooled from 500° C.
S 5 W	576.0	360.5	467.5	4.4	177.3	Water cooled from 500° C.
S 6 F	643.5	351.0	514.3	0	154.7	Furnace cooled from 600° C.
S 6 A	666.0	360.5	541.4	[1] 5.3	145.0	Air cooled from 600° C.
S 6 W	726.0	268.0	464.3	9.7	164.7	Water cooled from 600° C.
S 65 F	760.0	406.5	606.5	0	143.2	Furnace cooled from 650° C.
S 65 A	680.0	339.0	534.0	12.0	145.0	Air cooled from 650° C.
S 65 W	658.0	360.5	471.25	22.3	160.0	Water cooled from 650° C.
S 67 F	726.0	410.0	577.75	0	140.5	Furnace cooled from 675° C.
S 67 A	678.0	360.5	544.75	5.7	154.0	Air cooled from 675° C.
S 67 W	678.0	390.0	516.2	10.7	146.0	Water cooled from 675° C.
S 7 F	780.0	460.0	605.7	0	129.4	Furnace cooled from 700° C.
S 7 A	680.0	341.5	566.75	6.4	129.5	Air cooled from 700° C.
S 7 W	646.0	303.0	484.0	20.1	143.0	Water cooled from 700° C.
S C F	330.0	258.0	299.75	0	114.2	Furnace cooled from 725° C.
S C A	481.5	312.0	358.9	[1] 19.7	118.2	Air cooled from 725° C.
S C W	547.0	398.0	475.0	[1] 58.5	164.0	Water cooled from 725° C.

[1] Increased percentage.

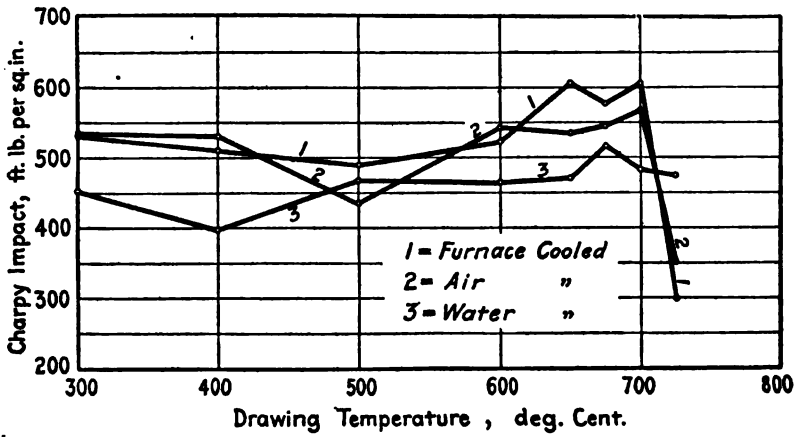
CONSIDERATION OF RESULTS.

An examination of these tables reveals the fact that in every case the average resistance to shock of the pieces water cooled after drawing is less than pieces treated identically but allowed to cool slowly in the furnace. This percentage decrease in resistance to shock varies from 4 to 22 per cent. In the case of the air-cooled pieces the resistance to shock is rather inconsistent, especially for the lower drawing temperatures. For the upper drawing temperatures the shock resistance of the air-cooled pieces lies between the furnace and water cooled specimens, as might be expected. In the case of the specimens drawn at 725° C. the water cooled shows the greatest resistance to shock, the air cooled next, and the furnace cooled the least. This is explainable on the ground that the pieces had reached the critical temperature, having passed through the range of drawing temperatures, and by water or air cooling a true hardening was given to the pieces.

The results are shown graphically in curve No. 1.

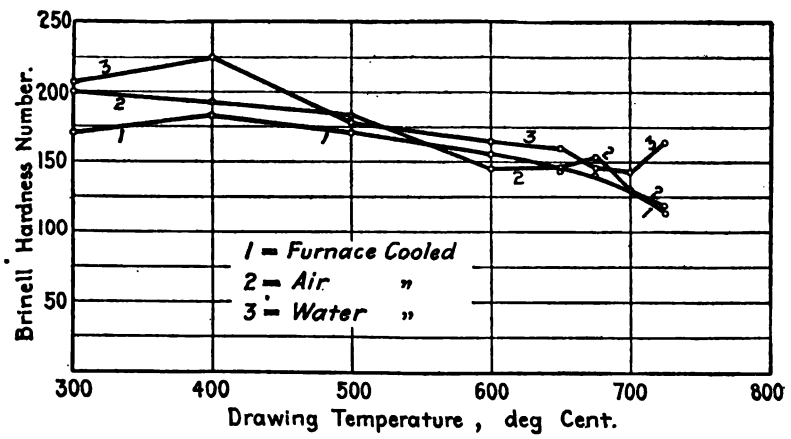
The results of Brinell hardness tests made on the broken Charpy specimens are given in tables No. 1 and No. 2, and plotted graphically in curve No. 2. All Brinell tests were made on an Alpha machine with a standard 10 mm. ball and a load of 2,000 kilograms. This reduced load was necessary on account of the small dimensions of the specimen.

It will be observed that the water-cooled specimens are consistently harder than those furnace cooled. No theoretical explanation of this fact is offered, as no satisfactory one has yet been reached.



—Effect of Rate of Cooling after Drawing on Resistance to Shock.

FIG. NO. 1.



Effect of Rate of Cooling After Drawing on Resistance to Shock.

FIG. NO. 2.

CONCLUSIONS.

1. It has been shown in the case of a 0.20 carbon steel which had been hardened and then drawn that the resistance to shock as measured by the transverse Charpy impact test falls off from 4 to 22 per cent for specimens which were water cooled after drawing, as compared with furnace-cooled specimens.

2. The hardness of such pieces as measured by the Brinell method is somewhat greater for the water-cooled specimens.

3. It seems probable that, since no change in carbon condition is effected by the rate of cooling after drawing, what has been shown for a 0.20 carbon steel likewise holds true in the case of all carbon steels.

THE EFFECT OF CARBON ON THE PHYSICAL PROPERTIES OF HEAT-TREATED CARBON STEEL.

OBJECT.

The experiments herein described were undertaken with a view to investigating thoroughly the influence of carbon on the tensile and impact physical properties of carbon steel. The original comprehensive plan included investigation of a series of steels with varying carbon contents over a wide range of heat treatments. These were to be studied as to their static tensile qualities, and also their resistance to shock as measured by the Charpy impact-bending test. A thorough metallographic examination was likewise included in the schedule. The Charpy tests and the metallographic examination have not been completed to date, and are accordingly withheld for another report. All heat treatments have, however, been made, and the static tensile tests have been completed. A description of the procedure of the experiment and the results thus far obtained are therefore reported herein.

CONCLUSIONS.

No attempt is made to draw general conclusions from these experiments, but the curves and the data are submitted as being of general importance and wide applicability.

COMPOSITION OF MATERIALS.

An attempt was made to secure steels increasing in carbon by increments of one-tenth of 1 per cent from 0.1 per cent up to 0.8 per cent, and from that composition to 1.6 per cent by increments of two-tenths of 1 per cent. Actually, however, steels of the composition given in Table No. 1 were procured, and as the carbon contents were arranged sufficiently well so that satisfactory curves could be drawn showing the relation between carbon content and other properties, these steels were used in the experiments.

TABLE No. 1.—*Chemical composition of steels used.*

Carbon.	Manganese.	Sulphur.	Phosphorous.	Silicon.	Chromium.
Per cent.	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*
0.14	0.45	0.035	0.018	0.131	None.
.18	.56	.043	.024	.132	None.
.32	.51	.027	.009	.128	None.
.46	.40	.050	.020	.144	None.
.49	.60	.028	.013	.127	None.
.57	.65	.028	.012	.167	None.
.71	.67	.035	.027	.147	None.
.83	.55	.028	.018	.152	None.
1.01	.39	.029	.016	.160	None.
1.22	.34	.031	.025	.181	None.
1.39	.20	.029	.015	.191	None.
1.46	.20	.035	.011	.133	0.35

It will be noted that the carbon content varies from 0.14 per cent to 1.46 per cent. The manganese content varies from 0.2 per cent to 0.67 per cent, the amounts of this element being normal for commercial steels. It was thought that the variations in manganese content were not great enough to seriously disturb the conclusions to be drawn as to the effect of carbon.

Curve No. 1 is an empirical one showing the relative values of the hardening properties of the carbon and the manganese in these steels. The ordinate scale is reduced to one quarter that of the abscissae scale, arbitrarily assuming that the hardening value of manganese is one-fourth that of carbon. This is an assumption often made in practice. The coordinates of any point on the curve represent then, the relative hardening effect of the carbon and the manganese in the steel.

HEAT TREATMENT.

No critical point determinations were made on these steels. The temperatures used in the heat treatments were based on the recommended annealing temperatures for rolled and forged carbon steel objects of the American Society for Testing Materials. (See A. S. T. M. Year Book, page 201.)

The recommended temperatures were plotted in the form of a curve, which is shown as Curve No. 2. The proper heat treating temperatures were then read from this curve.

The layout of heat treatments adopted was as follows: One tension specimen and four Charpy specimens being taken from each steel for each heat treatment.

Specimens were tested:

(*a*) As received. (Probably hot rolled.)
(*b*) After annealing.
(*c*) After hardening in water.
(*d*) After hardening in oil.
(*e*) After hardening in oil and drawing at 375° C.
(*f*) After hardening in oil and drawing at 460° C.
(*g*) After hardening in oil and drawing at 560° C.
(*h*) After hardening in oil and drawing at 650° C.

The annealing and hardening temperatures used for each steel were as follows:

Steel.	Annealing and hardening temperature.
	°C.
0.14 per cent C.....	866
.18 per cent C.....	858
.32 per cent C.....	836
.46 per cent C.....	819
.49 per cent C.....	816
.57 per cent C.....	809
.71 per cent C.....	800
.83 per cent C.....	795
1.01 per cent C.....	790
1.22 per cent C.....	790
1.39 per cent C.....	790
1.46 per cent C.....	790

The steels were originally received as 12 or 14 foot bars 1 inch in diameter. From these bars tensile and Charpy specimens were rough-machined and were left $\frac{1}{16}$ of an inch large on all dimensions. Threads were not cut on the tensile specimens nor were the Charpy bars notched. All specimens were to be finish-machined after heat treatment. All heatings were done in a small electrically heated, closed muffle furnace, which maintained a very uniform temperature throughout the heating chamber. The inside dimensions of the muffle were $3\frac{3}{4}$ by $5\frac{3}{8}$ by $11\frac{1}{2}$ inches.

The heating for annealing and hardening all specimens for each steel was done at one time. The procedure was as follows. The specimens were suitably arranged in the furnace when cold. A platinum-platinum rhodium thermocouple, whose hot junction was inserted in a sample of the steel being heated, was also arranged in the furnace. The muffle door was closed with fire brick and asbestos and the current turned on. It required approximately an hour and a half for the specimens to come to heat. They were held at the desired temperature for 20 minutes. The specimens to be hardened were then quenched in oil or water as indicated; those to be annealed were allowed to cool slowly with the furnace, the opening to the muffle being again closed. Approximately eight hours was required for the furnace and annealed specimens to reach atmospheric temperature.

The drawing operation was performed as follows: A cast-iron pot 12 by 12 by 12 inches inside dimensions was filled with a eutectic mixture of sodium and potassium nitrates and was heated by gas. The melting point of this mixture is low enough so that the bath was molten at the desired temperatures. The bath was raised to the desired temperature and the specimens introduced in a wire basket. They were maintained at the drawing temperature for 30 minutes.

All temperature measurements were made by means of platinum-platinum rhodium thermocouples and a Leeds and Northrup precision potentiometer. The thermocouples used were carefully calibrated before use.

Subsequent to heat treatment all specimens were finish-machined previous to testing. In the case of certain of the harder specimens, it was necessary to soften the ends so that a thread could be cut on them. This was accomplished without affecting the reduced section of the specimens by partially immersing them in water and playing a flame on the end to be softened.

TESTING.

All tensile tests were made on the 800,000 pounds Emery hydraulic principle testing machine in this laboratory. Brinell hardness tests were made on an Alpha machine under standard conditions; that is, using a 10-mm. ball, a load of 3,000 kilograms, and a time of application of 30 seconds.

DATA.

The results of the tensile and Brinell hardness tests are summarized in the following tables; while curves 3 to 10, inclusive, depict these results graphically, showing for each heat treatment the changes in physical properties due to increase in carbon

content. Curves Nos. 11, 12, and 13 show the changes in maximum strength, yield point, and Brinell hardness, respectively, with increasing drawing temperatures. Curves for the steels with different carbon content are shown on the same sheet so that the relation between them is readily apparent. There are appended hereto photographs of the fractures of the tension test specimens tested in this investigation. In all cases the specimens are arranged in increasing carbons from left to right, the heat treatments being indicated in the photographs.

DISCUSSION.

In plotting curves Nos. 3 to 10, inclusive, the observed points have been located and straight dotted lines drawn between them. Idealized curves have been drawn full, following the general shape of the dotted curves. Curve No. 5, showing the water-quenched specimens, is given for the sake of completeness. It is, however, of little value for in the case of all steels examined over 0.32 carbon, the unrelieved internal stresses doubtless caused irregular results to be obtained.

Maximum strength.—In the annealed condition, curve No. 4, the maximum unit strength reaches a maximum value at eutectoid composition; i. e., 0.83 per cent carbon, and then decreases slightly with increase of carbon. With the heat-treated steels, however, curves Nos. 6, 7, 8, 9, and 10, and also on curve No. 3 for hot-rolled steels, the falling off in maximum strength does not begin until a composition of 1.20 per cent carbon is reached. These curves show a rapid rise in tensile strength with increasing carbon to eutectoid composition, then a less rapid increase in strength to 1.20 per cent carbon, followed generally by a slight falling off. The increase in strength in most cases at 1.46 per cent carbon is to be attributed at least partially to the chromium content in this particular steel.

Yield point.—In all cases, except the hot-rolled condition, curve No. 3, the unit stress of the yield point reaches a maximum at eutectoid composition, falling off slightly or remaining constant with increase in carbon.

Brinell hardness.—The curves for Brinell hardness are similar in shape in nearly all cases to the curves for maximum strength.

Elongation and contraction.—In general the curves representing these two qualities show decreasing values with increasing carbon. The tendency of the curves is to be concave upwards; they are straighter, however, in the heat-treated steels than in the hot-rolled condition. On curves No. 4 and 6, that is, in the annealed and the plain oil-quenched conditions, the curves show a gain in ductility just beyond the eutectoid composition which is unaccountable.

Curves Nos. 11, 12, and 13 show the relation between the maximum strength, yield point, and Brinell hardness, respectively, and the drawing temperature after oil quenching for the various steels investigated. These curves show very nicely the relative effects of increasing carbon in connection with hardening and quenching treatments. The final points on all the curves represent the annealed condition of the metal. The curves are, therefore, shown dotted between these last points and a drawing temperature of 700° C.

TABLE II.—*Specimens tested as received.*

Per cent carbon.	Yield point (pounds per square inch).	Ultimate strength (pounds per square inch).	Elongation (per cent).	Contraction of area (per cent).	Brinell hardness No.
0.14	45,000	59,500	37.5	67.0	112
.18	45,000	63,000	36.0	67.0	118
.32	49,500	75,500	30.0	51.9	144
.46	52,500	86,500	22.5	30.7	160
.49	54,000	95,000	20.5	37.2	183
.57	57,000	106,500	19.0	27.4	220
.71	66,000	128,000	15.0	20.5	240
.83	70,500	139,000	12.5	13.3	269
1.01	86,000	152,000	9.5	13.3	302
1.22	77,500	151,500?	3.0?	.....	288
1.39	74,500	139,000	2.0	1.8	321
1.46	89,500	150,500	1.5	1.8	351

TABLE III.—*Specimens annealed.*

Per cent carbon.	Yield point (pounds per square inch).	Ultimate strength (pounds per square inch).	Elongation (per cent).	Contraction of area (per cent).	Brinell hardness No.
0.14	31,000	54,500	39.5	67.0	107
.18	39,500	59,000	36.5	67.0	111
.32	41,000	70,000	30.5	51.9	131
.46	48,000	79,500	28.5	46.2	153
.49	47,000	86,000	28.5	46.2	163
.57	50,000	95,000	25.0	40.3	183
.71	46,500	111,500	16.5	24.0	217
.83	50,500	114,000	15.0	20.5	223
1.01	53,800	99,400	24.0	36.2	192
1.22	49,000	100,000	24.5	40.3	196
1.39	51,500	98,000	15.5	20.5	202
1.46	52,000	106,000	18.5	20.5	212

TABLE IV.—*Specimens water quenched.*

Per cent carbon.	Yield point[1] (pounds per square inch).	Ultimate strength (pounds per square inch).	Elongation (per cent).	Contraction of area (per cent).	Brinell hardness No.
0.14	.....	90,000	21.0	67.0	170
.18	.....	105,000	16.5	57.2	228
.32	.....	135,500	8.0	16.9	255
.46	.....	220,000	1.0	0	600
.49	.....	183,000	0	0	713
.57	.....	215,000	0	0	578
.71	.....	.....	.....	.....	.....
.83	.....	93,000	0	0	744
1.01	.....	153,000	0	0	578
1.22	.....	166,000	0	1.8	555
1.39	.....	140,500	1.0	0	460
1.46	.....	181,500	0	0	627

[1] Not determined.

TABLE V.—*Specimens oil quenched.*

Per cent carbon.	Yield point (pounds per square inch).	Ultimate strength (pounds per square inch).	Elongation (per cent).	Contraction of area (per cent).	Brinell hardness No.
0.14	56,500	71,500	34.0	75.5	134
.18	54,500	78,700	31.0	75.2	156
.32	67,500	101,000	23.5	62.3	207
.46	87,500	126,500	20.5	51.9	255
.49	88,500	131,000	17.5	51.9	277
.57	105,000	152,000	16.5	40.3	311
.71	100,000	184,500	1.5	0	364
.83	138,500	184,500	4.0	5.7	418
1.01	127,000	192,500	10.5	34.0	387
1.22	122,500	201,500	9.0	16.9	402
1.39	97,500	188,500	2.5	5.7	430
1.46	122,500	201,500	3.5	5.7	418

TABLE VI.—*Specimens oil quenched and drawn at 375° C.*

Per cent carbon.	Yield point (pounds per square inch).	Ultimate strength (pounds per square inch).	Elongation (per cent).	Contraction of area (per cent).	Brinell hardness No.
0.14	49,000	68,500	38.0	75.5	131
.18	56,000	76,000	29.5	73.5	149
.32	68,000	100,500	22.5	62.3	223
.46	85,500	125,000	20.0	51.9	255
.49	91,000	135,500	20.5	51.9	277
.57	106,500	153,000	16.0	43.3	302
.71	121,400	179,100	3.5	.....	375
.83	.....	198,500	11.5	34.0	364
1.01	127,500	195,000	12.5	34.0	375
1.22	131,000	203,000	8.0	13.3	402
1.39	125,000	178,500	2.5	5.7	418
1.46	133,000	196,000	3.5	.....	387

TABLE VII.—*Specimens oil quenched and drawn at 460° C.*

Per cent carbon.	Yield point (pounds per square inch).	Ultimate strength (pounds per square inch).	Elongation (per cent).	Contraction of area (per cent).	Brinell hardness No.
0.14	53,000	68,500	36.0	75.5	134
.18	58,500	75,500	32.5	71.4	149
.32	67,000	99,000	23.0	62.3	187
.46	86,000	123,500	19.5	51.9	228
.49	85,500	127,000	18.5	51.9	235
.57	97,500	145,500	16.0	46.2	293
.71	115,500	177,000	10.0	34.0	340
.83	134,000	194,500	14.0	37.2	387
1.01	111,000	201,500	12.5	40.3	402
1.22	122,500	199,000	8.5	13.3	418
1.39	123,500	134,000	3.5	.....	402
1.46	139,000	197,000	2.5	.....	430

TABLE VIII.—*Specimens oil quenched and drawn at 560° C.*

Per cent carbon.	Yield point (pounds per square inch).	Ultimate strength (pounds per square inch).	Elongation (per cent).	Contraction of area (per cent).	Brinell hardness No.
0.14	49,000	66,000	35.0	75.5	126
.18	56,500	72,500	33.5	75.5	146
.32	66,000	92,500	26.5	64.7	183
.46	81,500	111,500	24.0	57.2	202
.49	77,500	116,000	23.5	57.2	228
.57	93,500	133,000	20.5	51.9	255
.71	106,000	148,500	17.0	43.3	311
.83	.....	161,000	19.0	40.3	321
1.01	104,500	168,500	14.5	30.7	321
1.22	106,000	171,500	11.5	20.5	351
1.39	101,500	161,000	4.0	5.7	332
1.46	111,000	178,500	4.0	.....	375

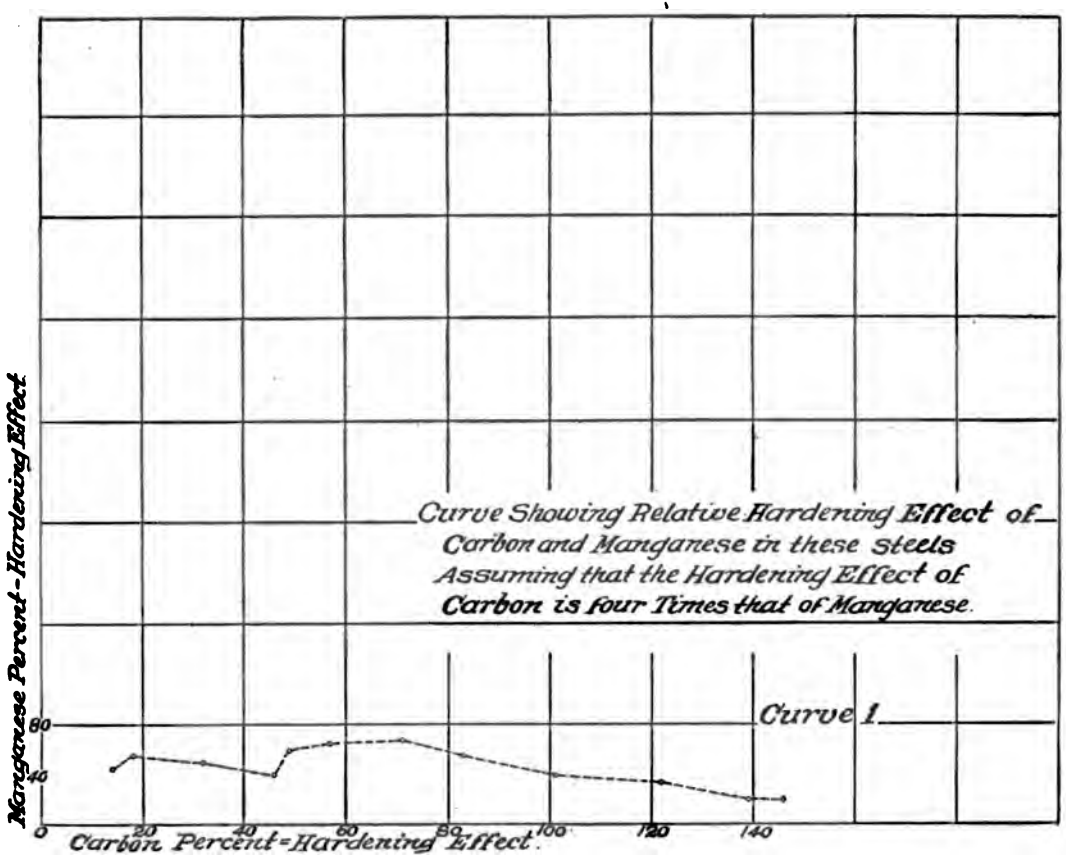
TABLE IX.—*Specimens oil quenched and drawn at 650° C.*

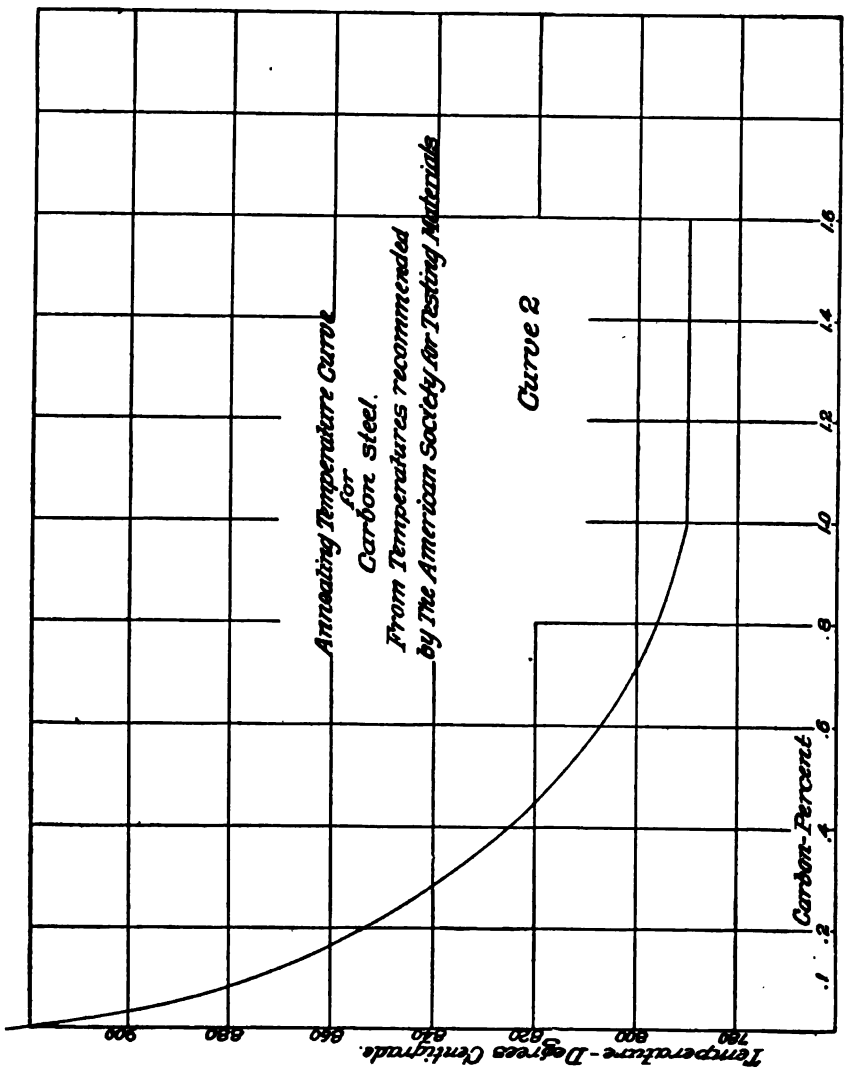
Per cent carbon.	Yield point (pounds per square inch).	Ultimate strength (pounds per square inch).	Elongation (per cent).	Contraction of area (per cent).	Brinell hardness No.
0.14	46,500	64,000	38.5	79.5	118
.18	51,500	69,000	36.0	75.5	134
.32	61,500	84,000	30.0	71.4	163
.46	73,000	98,000	25.5	59.8	192
.49	76,500	107,500	26.0	62.3	217
.57	79,500	113,500	24.0	62.3	228
.71	91,000	125,000	19.5	57.2	269
.83	97,500	129,000	19.0	46.2	277
1.01	86,000	134,000	20.0	40.3	277
1.22	88,000	139,500	15.5	34.0	269
1.39	85,500	131,500	11.0	16.9	269
1.46	95,500	159,500	11.0	13.3	321

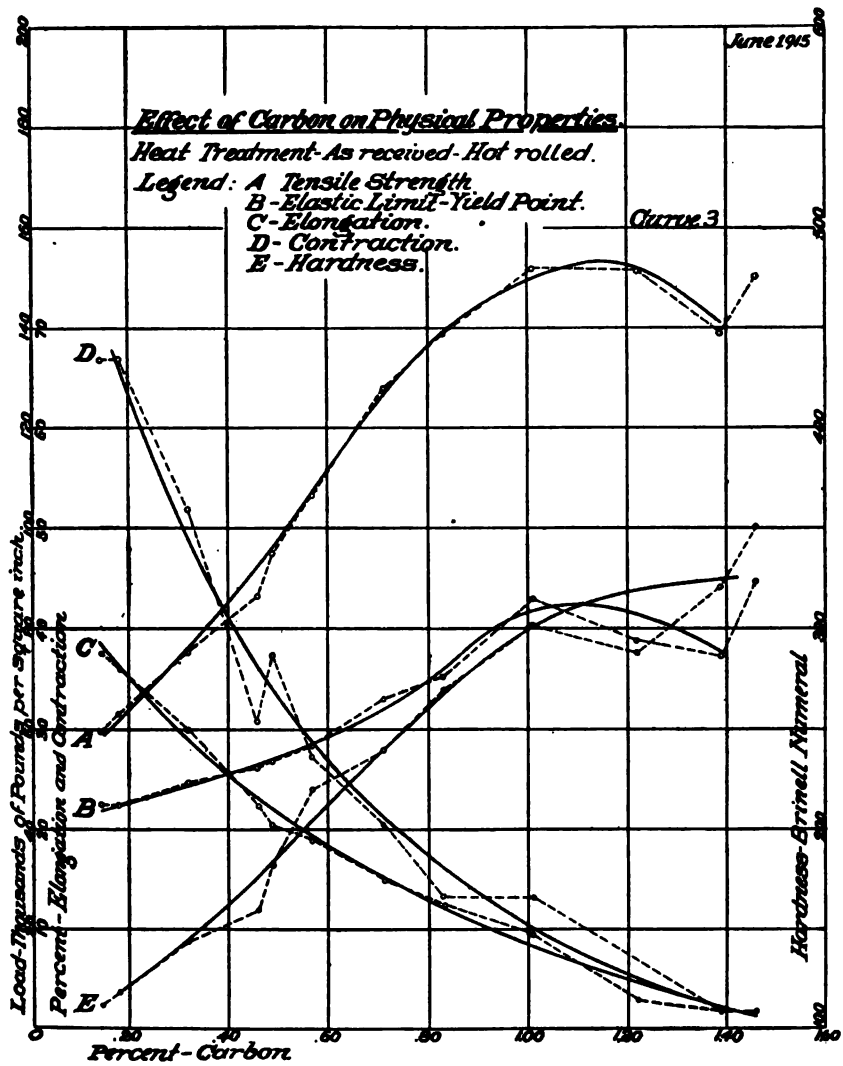
APPENDIX.

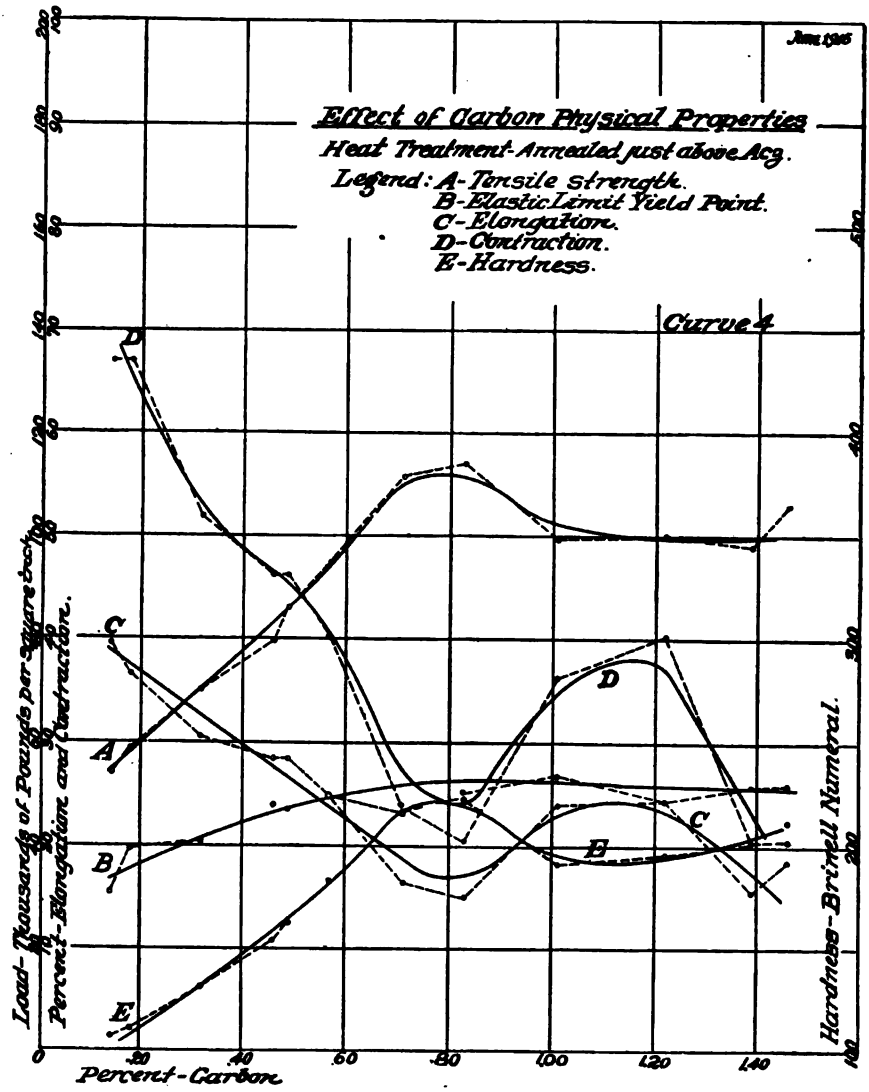
The following photomicrographs are presented as being of considerable interest in connection with the preceding experiments. The 12 steels investigated are shown in two different conditions, viz, (1) as received, hot rolled, and (2) normalized or annealed from 1,000° C. In the normalized series the effect of carbon on the microstructure is most readily apparent. This arrangement of micrographs on pages should be carefully checked with original proof.

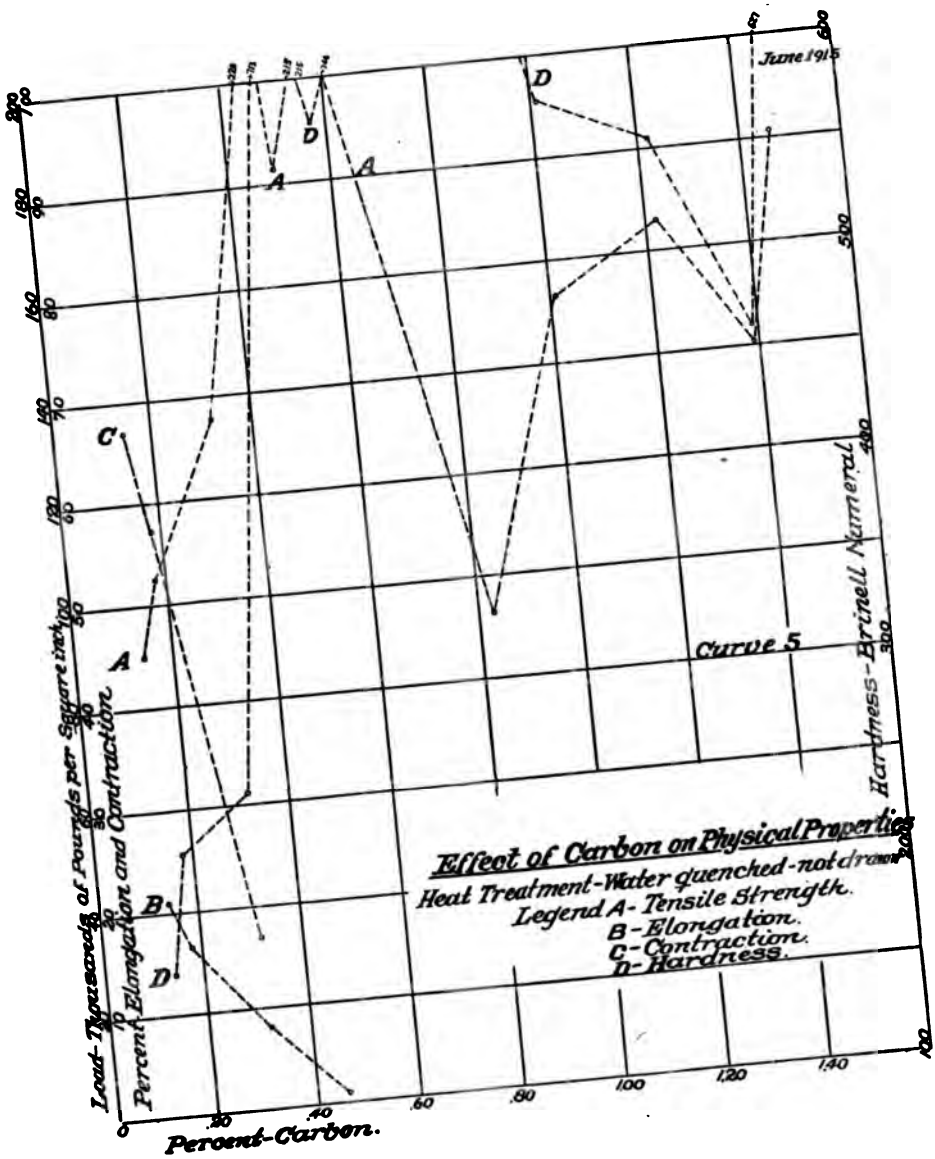
In the case of the hot-rolled steels, the structures consist of sorbito-pearlite and ferrite for the hypoeutectoid steels and sorbito-pearlite and cementite for the hypereutectoid steels. In the case of the normalized steels, the grain structures are considerably larger and the constituents are pearlite and ferrite for hypoeutectoid steels and pearlite and cementite for hypereutectoid steels. All micrographs are magnified 75 diameters.

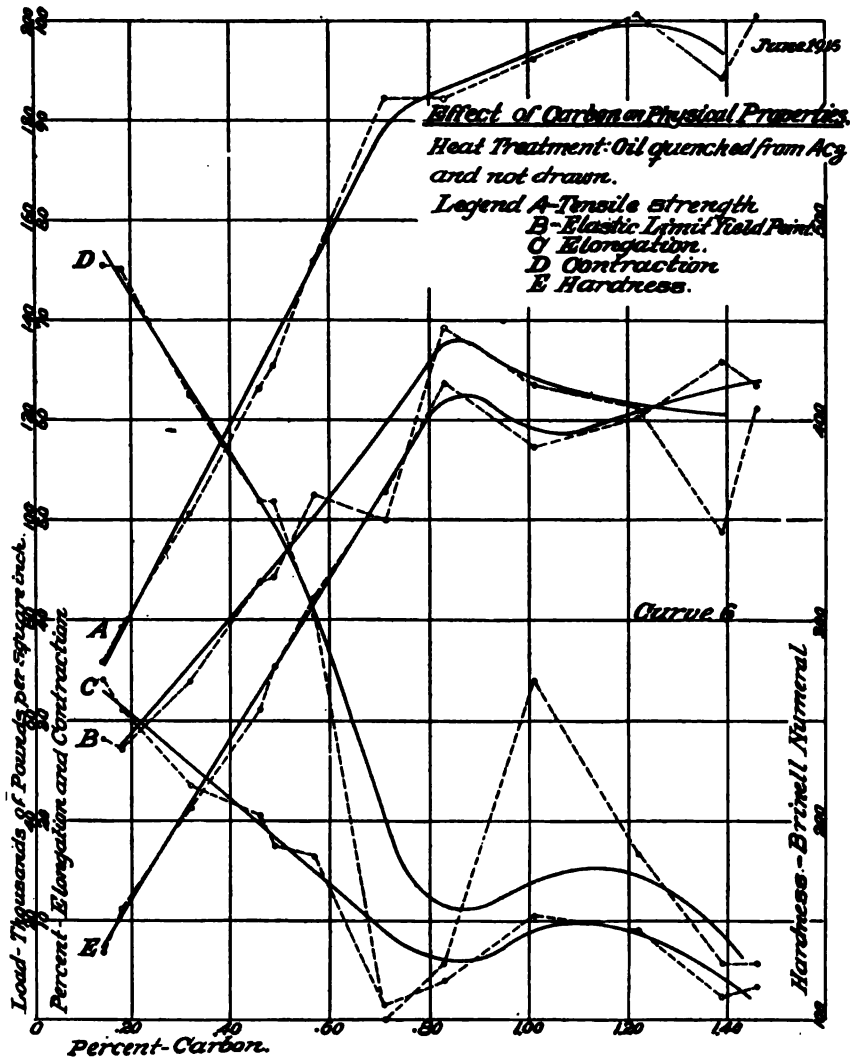

Curve Showing Relative Hardening Effect of
Carbon and Manganese in these Steels
Assuming that the Hardening Effect of
Carbon is four Times that of Manganese.
Curve 1.
Manganese Percent = Hardening Effect.
80
40
0
20
40
60
80
100
120
140
Carbon Percent = Hardening Effect.

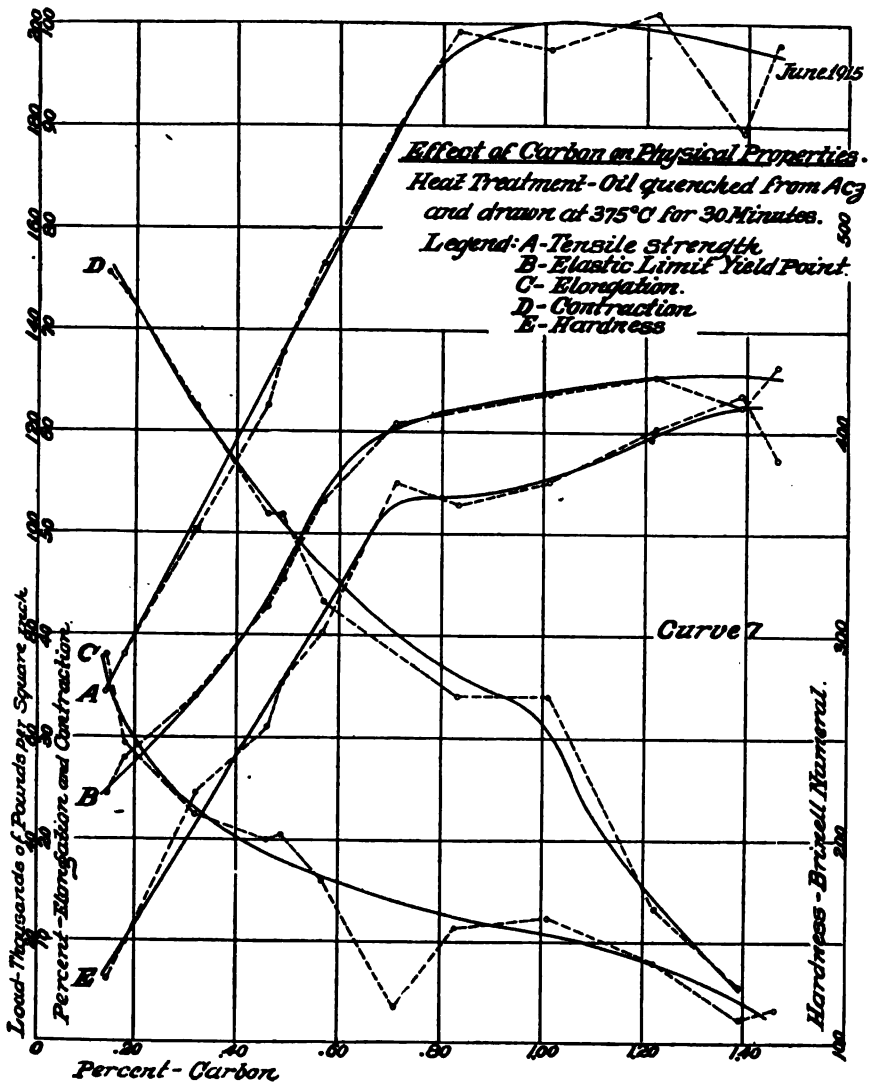

Annealing Temperature Curve
for
Carbon steel.
From Temperatures recommended
by The American Society for Testing Materials
Curve 2
Carbon-Percent
.1 .2 .4 .6 .8 1.0 1.2 1.4 1.6
Temperature - Degrees Centigrade.
780 800 820 840 860 880 900

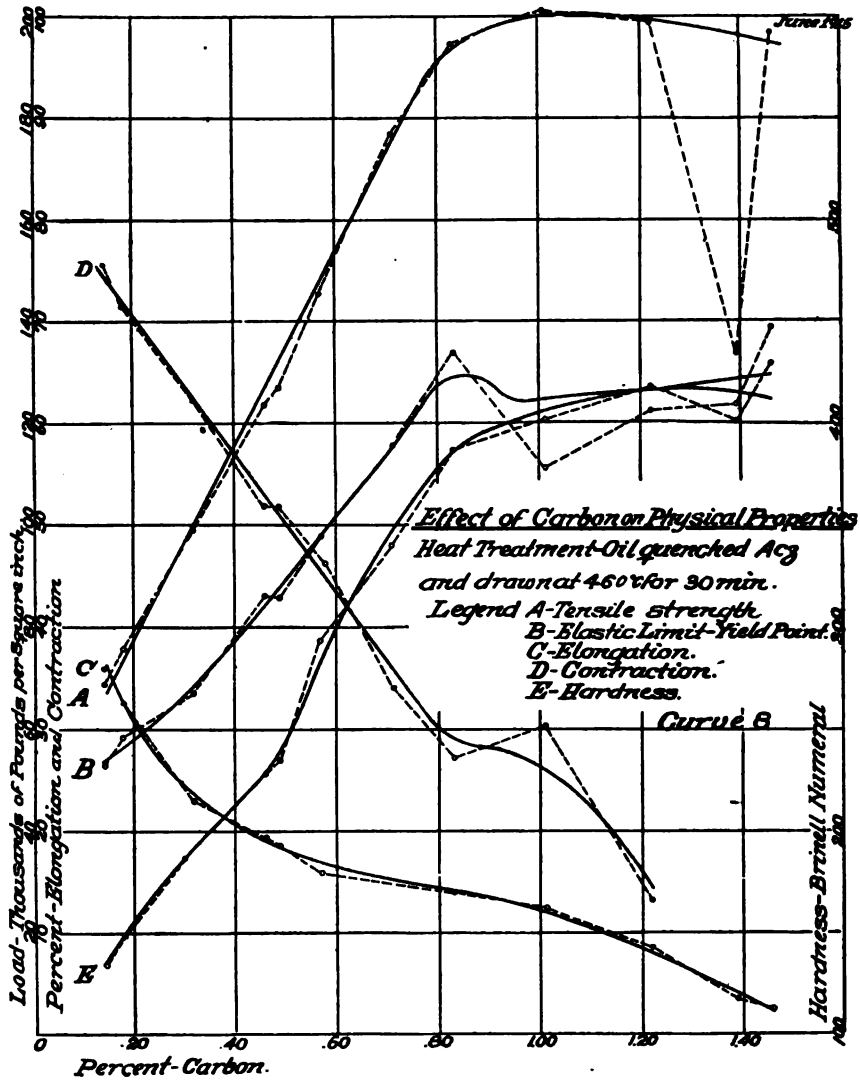

June 1915
Effect of Carbon on Physical Properties.
Heat Treatment-As received-Hot rolled.
Legend: A Tensile Strength
B-Elastic Limit-Yield Point.
C-Elongation.
D-Contraction.
E-Hardness.
Curve 3
D
C
A
B
E
Load-Thousands of Pounds per Square inch
Percent-Elongation and Contraction
Hardness-Brinell Numeral
Percent-Carbon
.20
.40
.60
.80
1.00
1.20
1.40

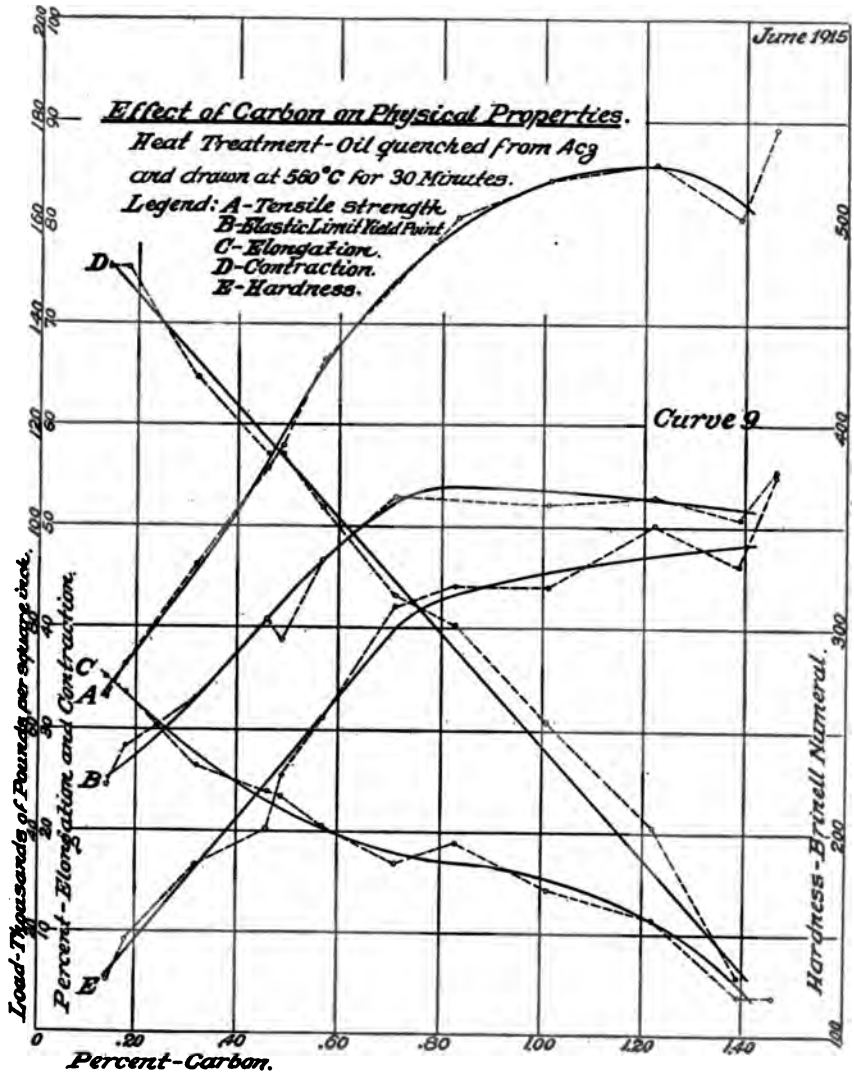

Effect of Carbon Physical Properties
Heat Treatment-Annealed just above Acg.
Legend: A-Tensile Strength.
B-Elastic Limit Yield Point.
C-Elongation.
D-Contraction.
E-Hardness.
Curve 4
Load-Thousands of Pounds per Square Inch
Percent-Elongation and Contraction.
Hardness-Brinell Numeral.
Percent-Carbon
0
.20
.40
.60
.80
1.00
1.20
1.40
A
B
C
D
E

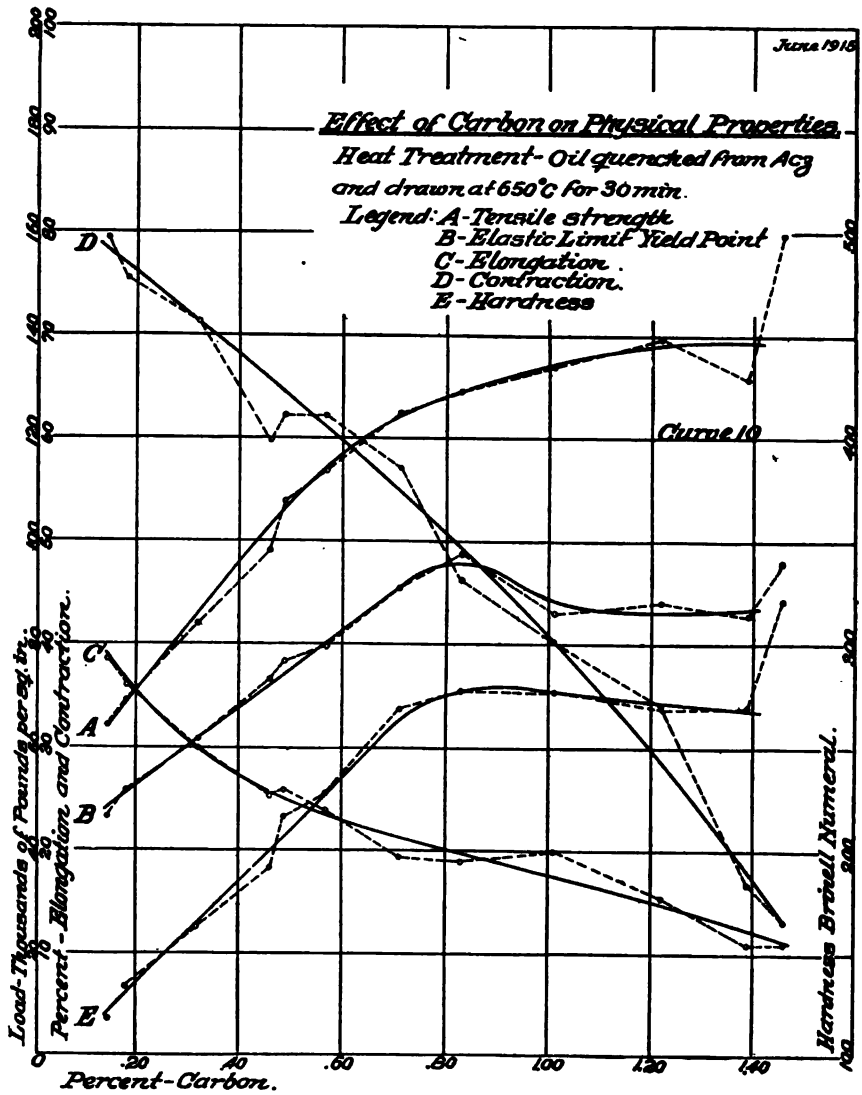

June 1915
Curve 5
Effect of Carbon on Physical Properties
Heat Treatment-Water quenched-not drawn
Legend A-Tensile Strength.
B-Elongation.
C-Contraction.
D-Hardness.
Load-Thousands of Pounds per Square inch
Percent Elongation and Contraction
Hardness-Brinell Numeral
Percent-Carbon.
A
B
C
D

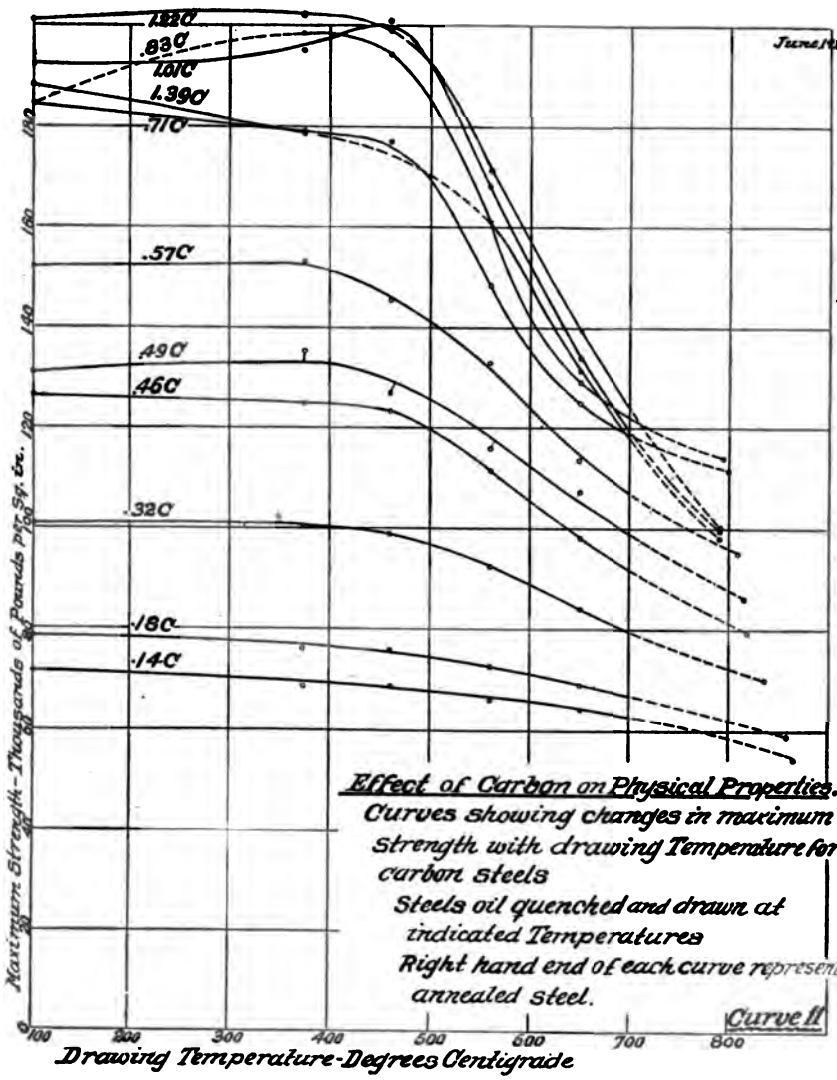

Effect of Carbon on Physical Properties.
Heat Treatment: Oil quenched from Acy and not drawn.
Legend A-Tensile strength
B-Elastic Limit Yield Point
C Elongation.
D Contraction
E Hardness.
Curve 6
A
B
C
D
E
Load-Thousands of Pounds per square inch.
Percent-Elongation and Contraction
Hardness-Brinell Numeral
Percent-Carbon.
0
.20
.40
.60
.80
1.00
1.20
1.40

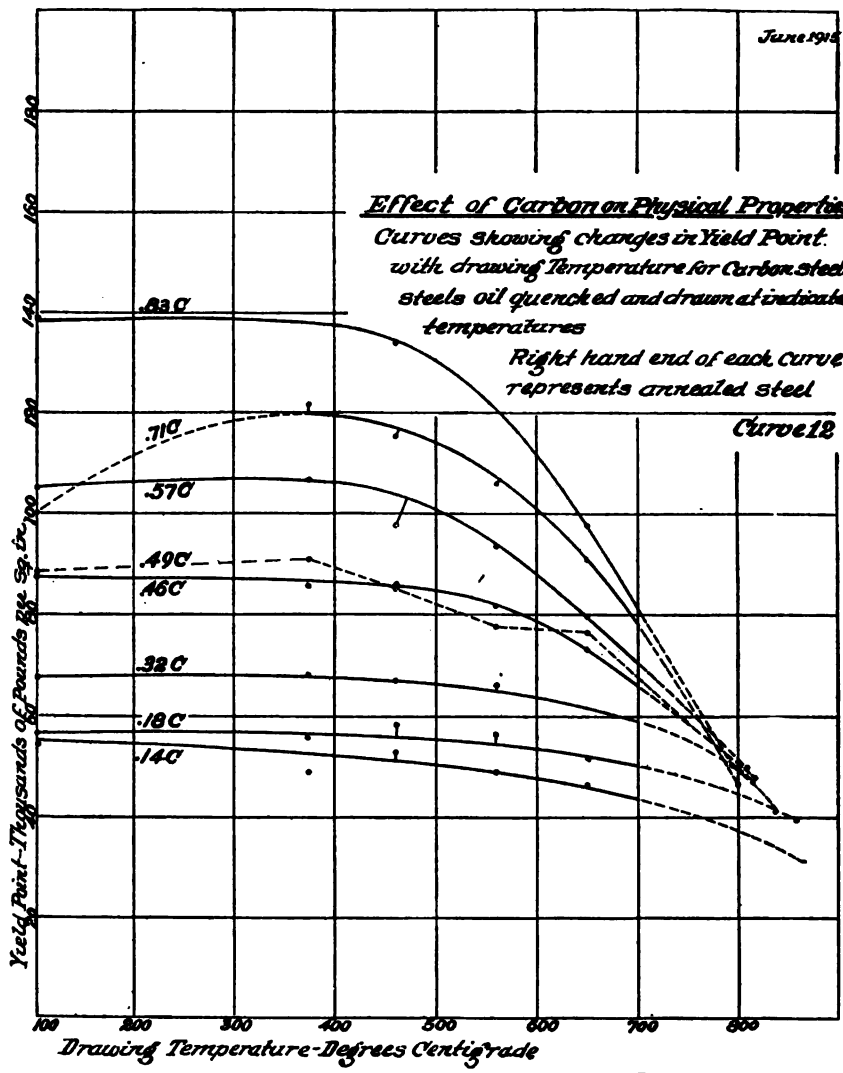

June 1915
Effect of Carbon on Physical Properties.
Heat Treatment - Oil quenched from Ac3
and drawn at 375°C for 30 Minutes.
Legend: A - Tensile Strength
B - Elastic Limit Yield Point
C - Elongation.
D - Contraction
E - Hardness
Curve 7
Load - Thousands of Pounds per Square Inch.
Percent - Elongation and Contraction.
Hardness - Brinell Numeral.
Percent - Carbon
0
.20
.40
.60
.80
1.00
1.20
1.40
A
B
C
D
E

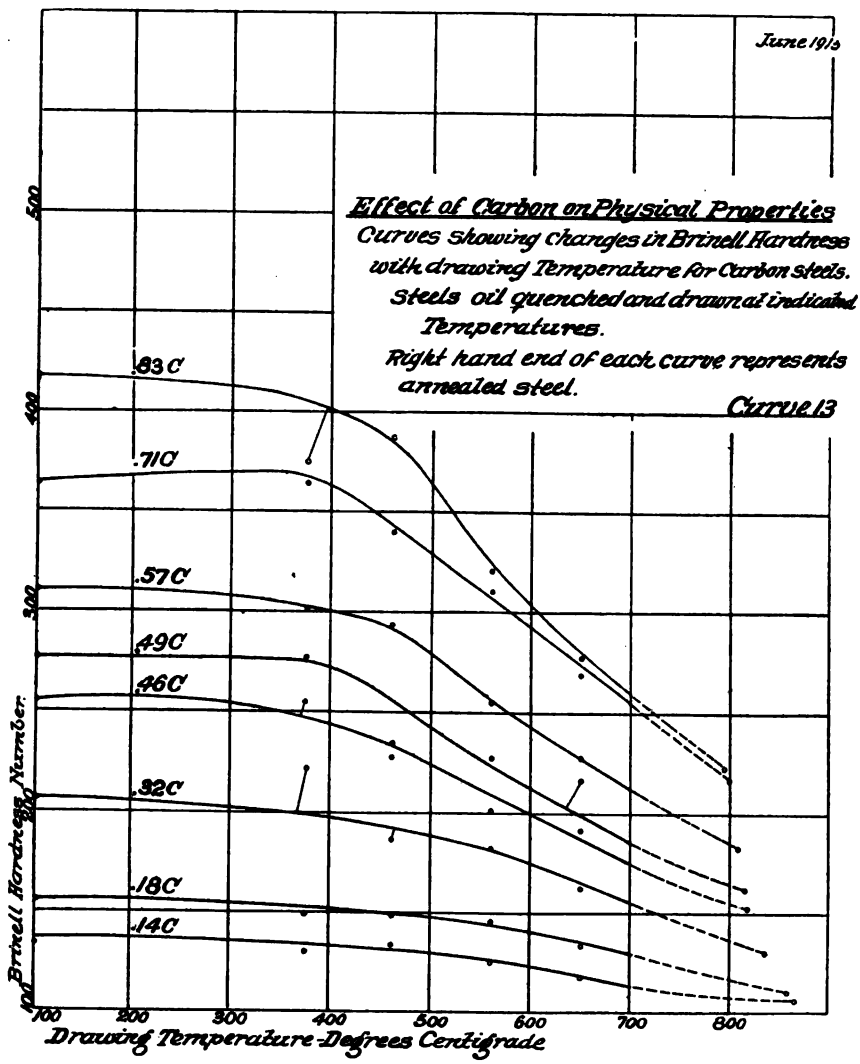

Effect of Carbon on Physical Properties
Heat Treatment-Oil quenched Acz
and drawn at 460°C for 30 min.
Legend A-Tensile Strength
B-Elastic Limit-Yield Point.
C-Elongation.
D-Contraction.
E-Hardness.
Curve 6
Load-Thousands of Pounds per Square Inch
Percent-Elongation and Contraction
Hardness-Brinell Numeral
Percent-Carbon.
A
B
C
D
E
0
.20
.40
.60
.80
1.00
1.20
1.40


June 1915
Effect of Carbon on Physical Properties.
Heat Treatment - Oil quenched from Ac3
and drawn at 560°C for 30 Minutes.
Legend: A-Tensile Strength.
B-Elastic Limit Yield Point.
C-Elongation.
D-Contraction.
E-Hardness.
Curve 9
Load-Thousands of Pounds per square inch.
Percent-Elongation and Contraction.
Hardness-Brinell Numeral.
Percent-Carbon.
0
.20
.40
.60
.80
1.00
1.20
1.40


June 1915
Effect of Carbon on Physical Properties.
Heat Treatment - Oil quenched from Acg
and drawn at 650°C for 30 min.
Legend: A-Tensile strength
B-Elastic Limit Yield Point
C-Elongation.
D-Contraction.
E-Hardness
Curve 10
D
C
A
B
E
Load-Thousands of Pounds per sq. in.
Percent-Elongation and Contraction.
Hardness Brinell Numeral.
Percent-Carbon.
.20
.40
.60
.80
1.00
1.20
1.40


1.22C
.83C
1.01C
1.39C
.71C
.57C
.49C
.45C
.32C
.18C
.14C
June 1915
Maximum Strength - Thousands of Pounds per Sq. in.
0
20
40
60
80
100
120
140
160
180
100
200
300
400
500
600
700
800
Drawing Temperature - Degrees Centigrade
Effect of Carbon on Physical Properties.
Curves showing changes in maximum strength with drawing Temperature for carbon steels
Steels oil quenched and drawn at indicated Temperatures
Right hand end of each curve represents annealed steel.
Curve II


June 1915
Effect of Carbon on Physical Properties.
Curves showing changes in Yield Point with drawing Temperature for Carbon Steels
Steels oil quenched and drawn at indicated temperatures
Right hand end of each Curve represents annealed Steel
Curve 12
.83 C
.71 C
.57 C
.49 C
.46 C
.32 C
.18 C
.14 C
Yield Point-Thousands of Pounds Per Sq. In.
Drawing Temperature-Degrees Centigrade


June 1913
Effect of Carbon on Physical Properties
Curves showing changes in Brinell Hardness with drawing Temperature for Carbon Steels.
Steels oil quenched and drawn at indicated Temperatures.
Right hand end of each curve represents annealed steel.
Curve 13
.83 C
.71 C
.57 C
.49 C
.46 C
.32 C
.18 C
.14 C
500
400
300
200
100
Brinell Hardness Number.
100
200
300
400
500
600
700
800
Drawing Temperature - Degrees Centigrade

EFFECT OF THE TIME OF HOLDING AT ANNEALING TEMPERATURE ON THE GRAIN SIZE AND THE PHYSICAL PROPERTIES OF HYPOEUTECTOID CARBON STEEL.

This experiment was undertaken to determine the effect of time of holding at annealing temperature on the grain size and the physical properties of hypoeutectoid carbon steel. The practical value of the experiment is evident. If it could be shown that there existed a critical duration of time for annealing—that is, a length of time of holding at annealing temperature which would give maximum physical properties together with minimum grain size—then that would be a basis for determining the length of annealing heats. If, on the other hand, it could be shown that physical properties and grain size were not affected by time of annealing but were entirely a function of temperature, then those results also would be of value.

It is a question among various metallurists as to just what factors determine grain size during annealing. It is generally conceded that temperature is the maximum consideration, but the effect of time at heat is in dispute.

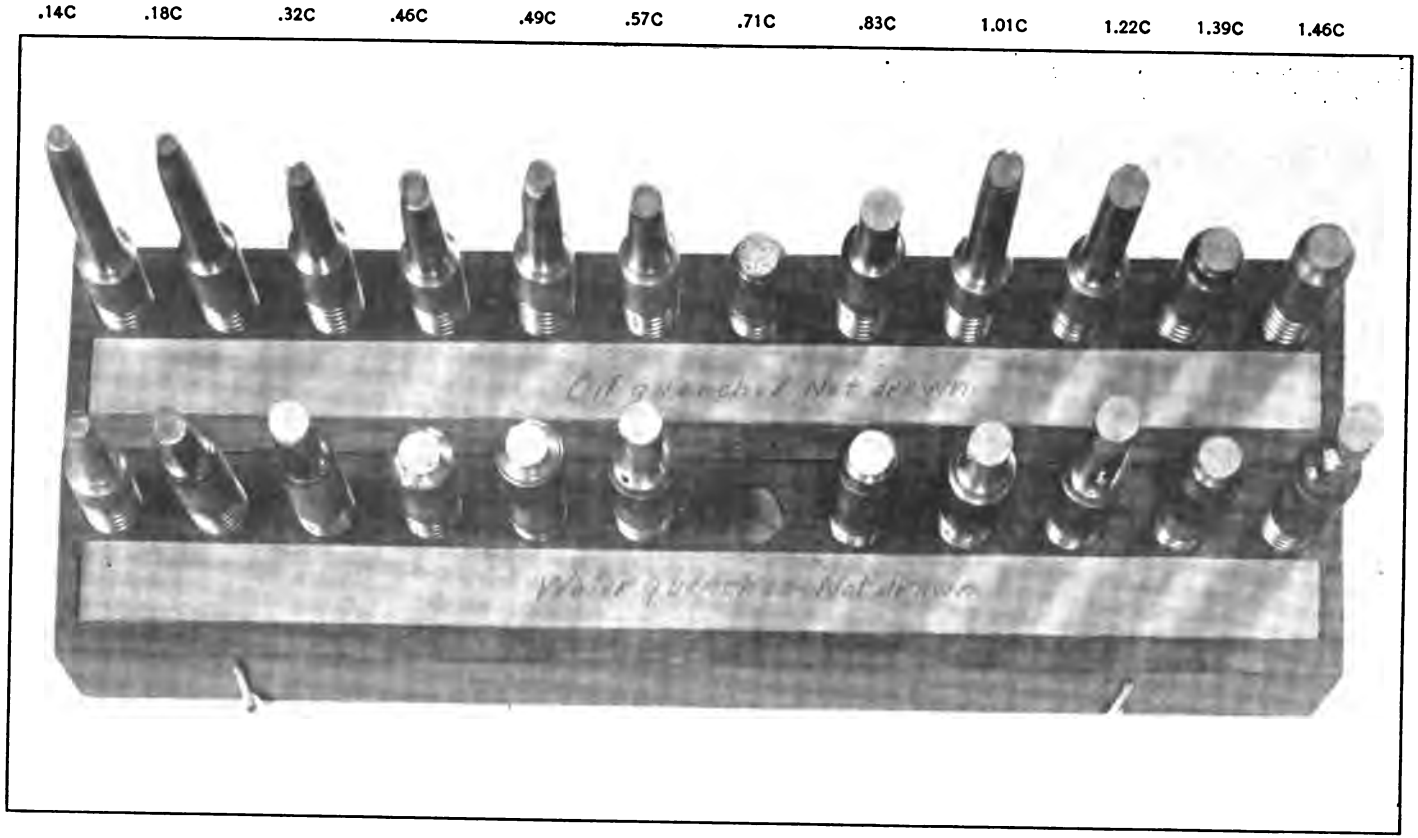
METHOD AND MANIPULATION.

For the experiment a 12-inch diameter ingot of Watertown Arsenal regular No. 3 cast steel was forged down to 1 inch round bars. Conditions of forging were kept as constant as possible, as were also the temperatures of the finishing of the forging operation. All bars were finish forged at as near 725° C. as possible. The chemical composition of the ingot was as follows:

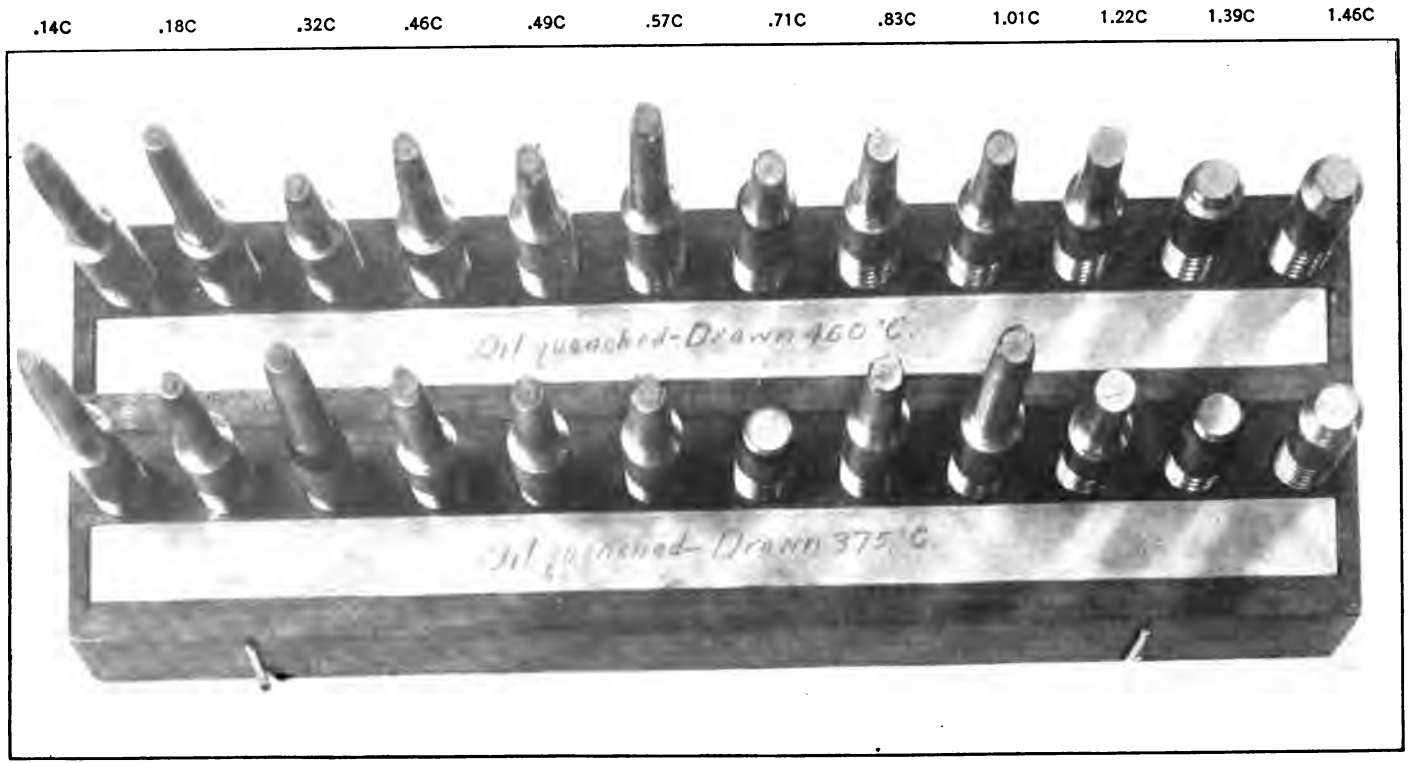
	Per cent.
Carbon	0.45
Manganese	.63
Silicon	.25
Sulphur	.055
Phosphorus	.038

Test pieces 8 inches long were cut from these 1-inch round bars. These test pieces were long enough for a standard tensile test specimen, and two Charpy impact bars. A heating and cooling curve of this steel was taken to determine the proper annealing temperature. This curve showed the critical temperature as 740° C. In accordance with this, a temperature 20° C. above this point, or 760° C., was adopted as the temperature for holding the pieces. The furnace used for heating was one of the laboratory experimental electric muffle furnaces which maintained a very uniform temperature throughout the heating chamber. All temperatures were measured by means of the precision potentiometer with a previously calibrated rare metal thermocouple.

The length of time of holding at temperature varied from one to ten hours, increasing the periods one hour at a time; that is, pieces

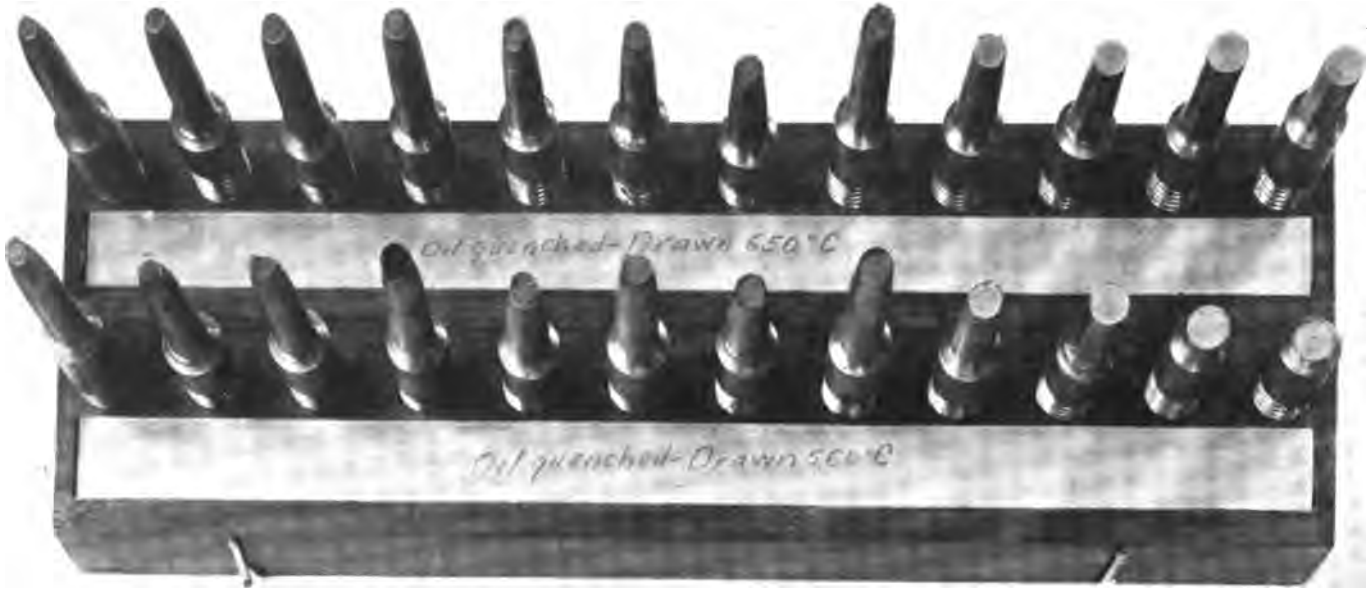


PHOTOGRAPH NO. 1.



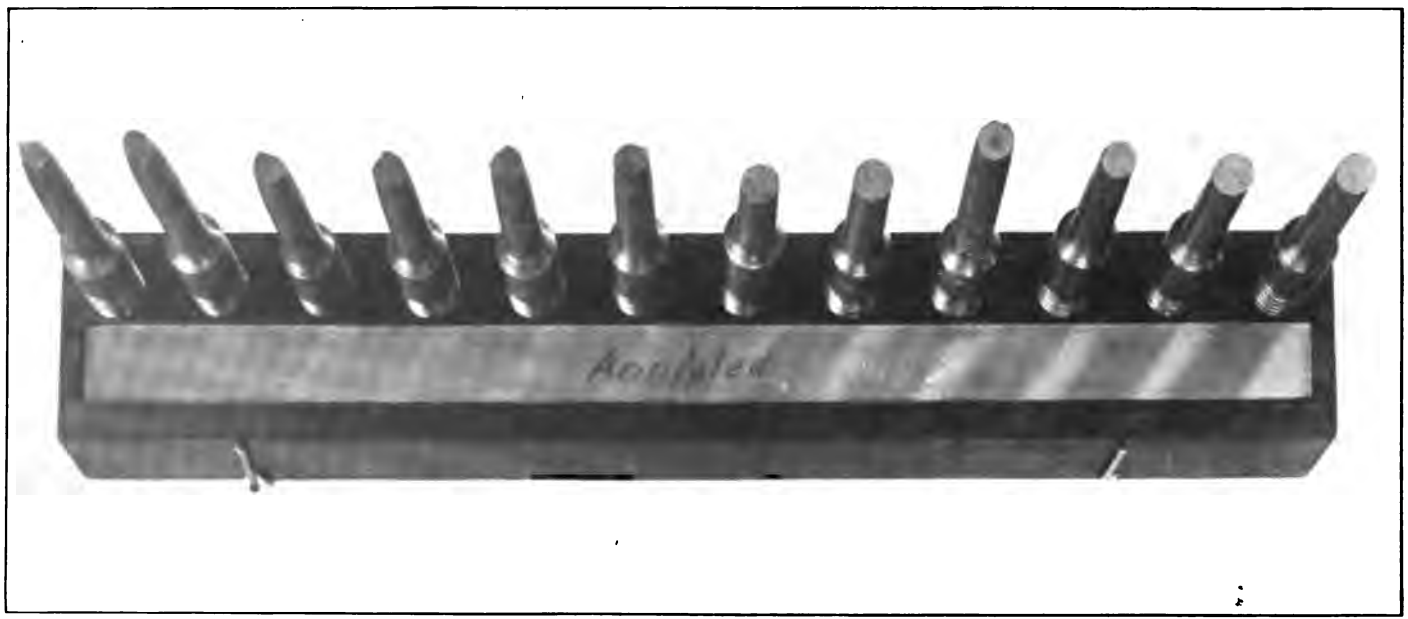
PHOTOGRAPH NO. 2.

.14C .18C .32C .46C .49C .57C .71C .83C 1.01C 1.22C 1.39C 1.46C

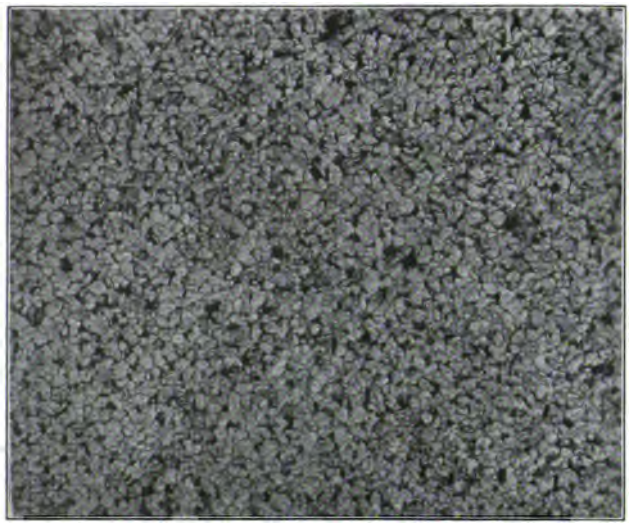


PHOTOGRAPH NO. 3.

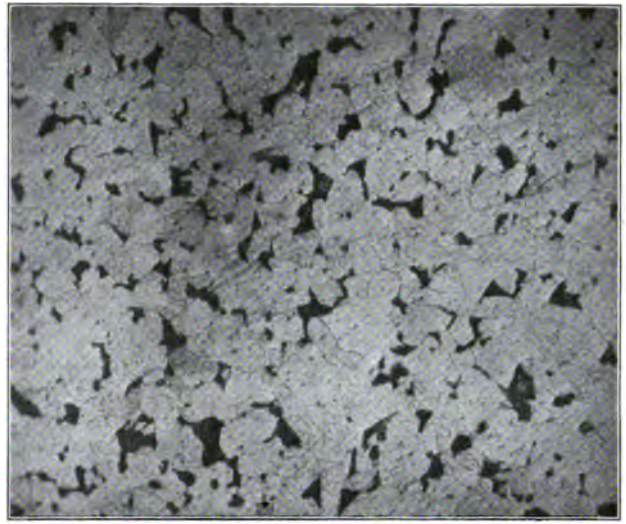
.14C .18C .32C .46C .49C .57C .71C .83C 1.01C 1.22C 1.39C 1.46C



PHOTOGRAPH NO. 4.

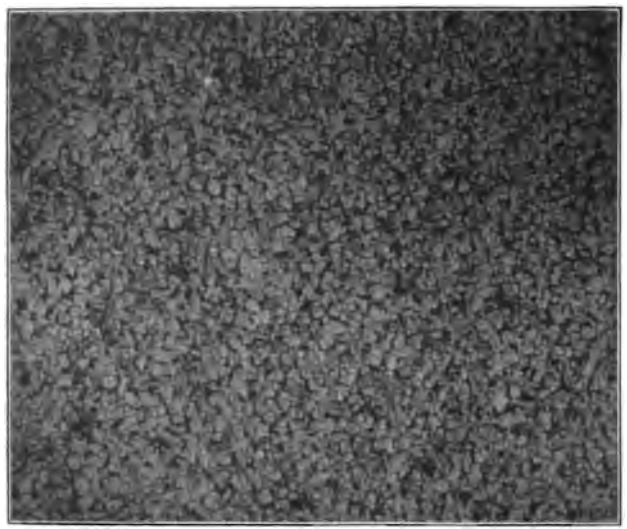


AS RECEIVED. HOT ROLLED. BRINELL HARDNESS=112.

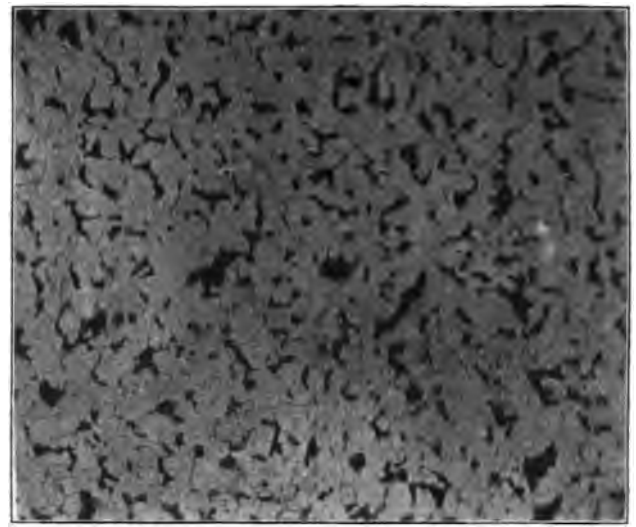


NORMALIZED. ANNEALED FROM 1,000° C. BRINELL HARDNESS=107.

	Per cent.
C	.14
Mn	.45
Si	.131
S	.035
P	.018

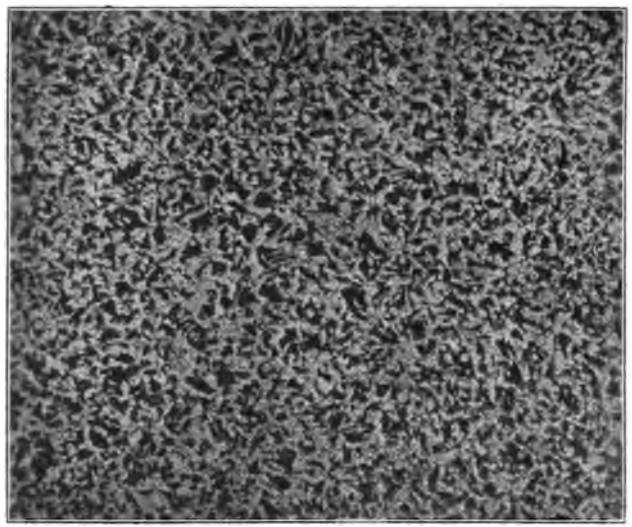


AS RECEIVED. HOT ROLLED. BRINELL HARDNESS=118.

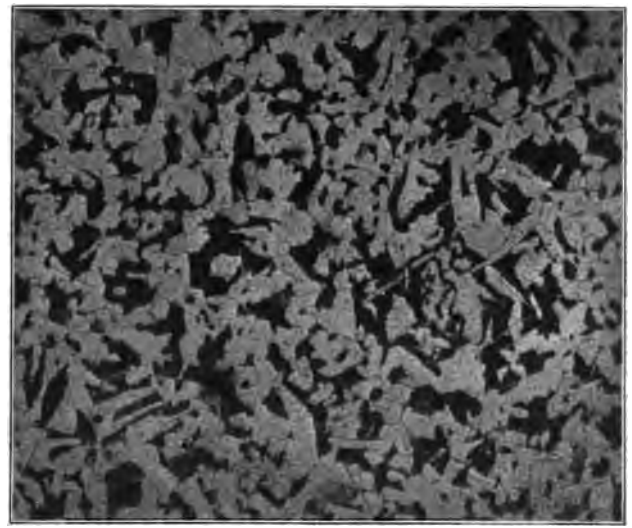


NORMALIZED. ANNEALED FROM 1,000° C. BRINELL HARDNESS=111.

	Per cent.
C	.18
Mn	.56
Si	.132
S	.043
P	.024

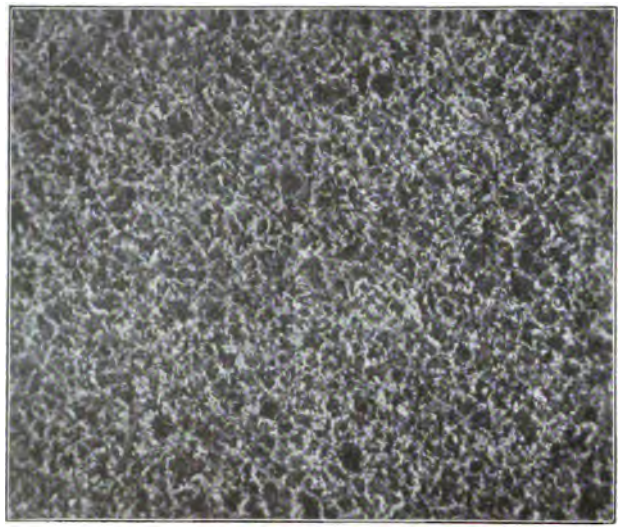


AS RECEIVED. HOT ROLLED. BRINELL HARDNESS=144.

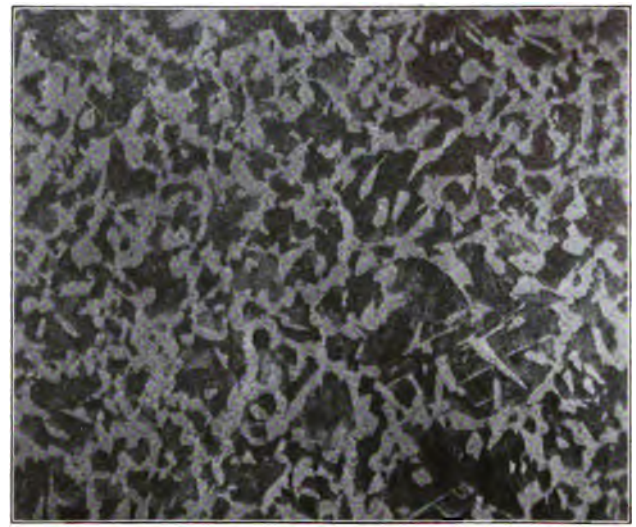


NORMALIZED. ANNEALED FROM 1,000° C. BRINELL HARDNESS=134.

	Per cent.
C	.32
Mn	.51
Si	.128
S	.027
P	.009

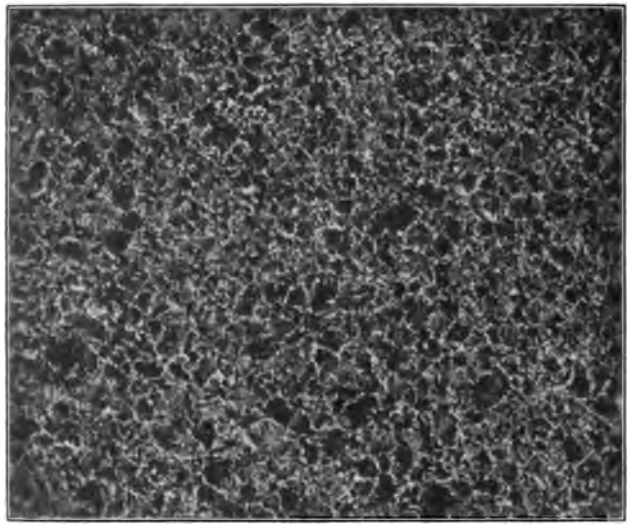


AS RECEIVED. HOT ROLLED. BRINELL HARDNESS=160.

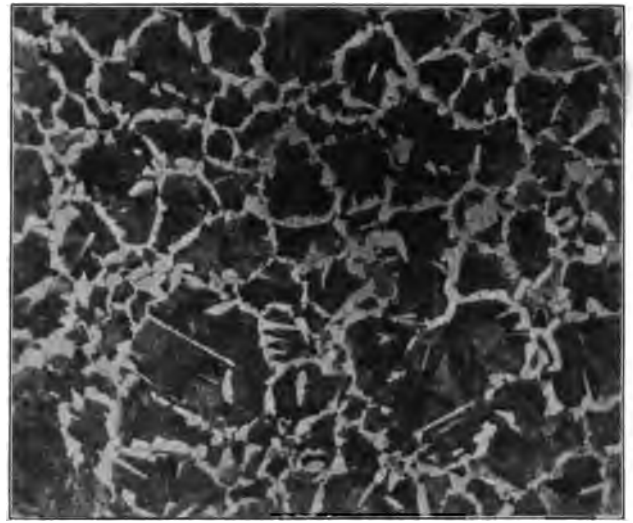


NORMALIZED. ANNEALED FROM 1,000° C. BRINELL HARDNESS=155.

	Per cent.
C	.46
Mn	.40
Si	.144
S	.050
P	.020

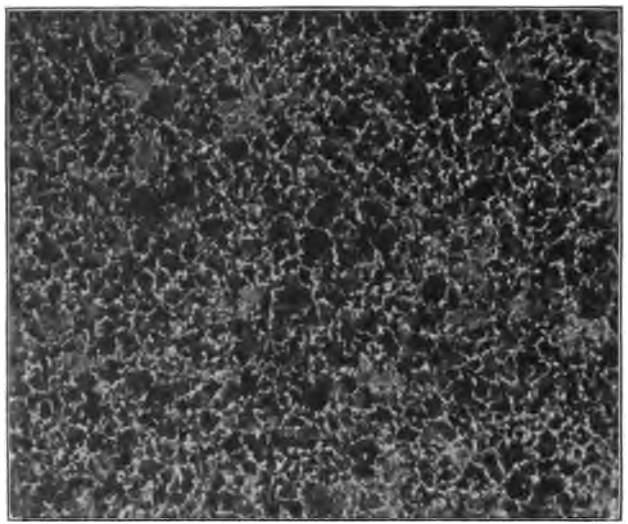


AS RECEIVED. HOT ROLLED. BRINELL HARDNESS=183.

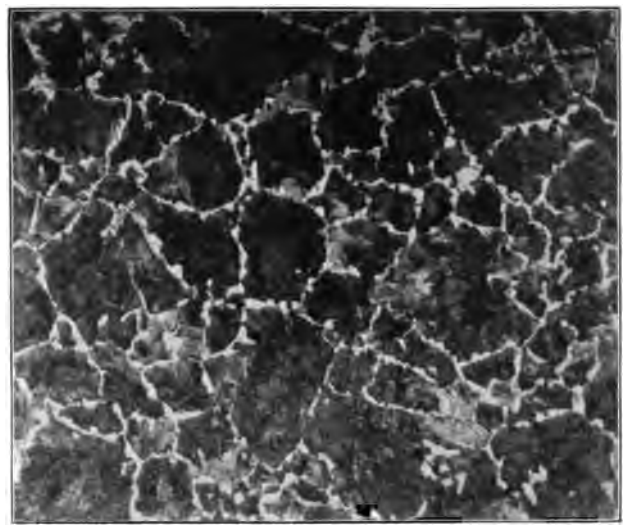


NORMALIZED. ANNEALED FROM 1,000° C. BRINELL HARDNESS=179.

	Per cent.
C	.49
Mn	.60
Si	.127
S	.028
P	.013



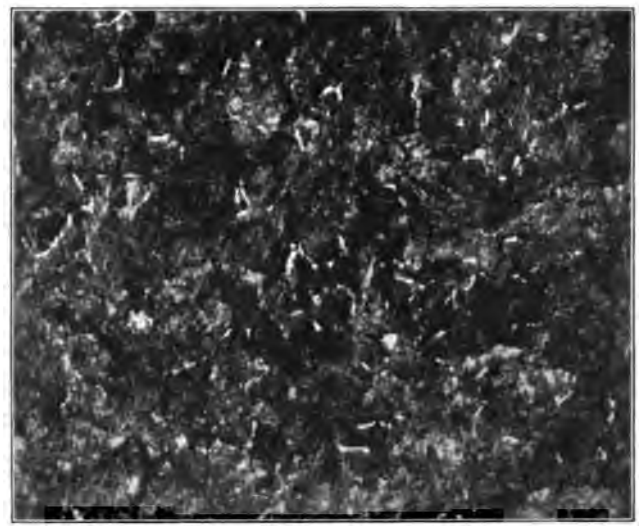
AS RECEIVED. HOT ROLLED. BRINELL HARDNESS=220.



NORMALIZED. ANNEALED FROM 1,000° C. BRINELL HARDNESS=206.

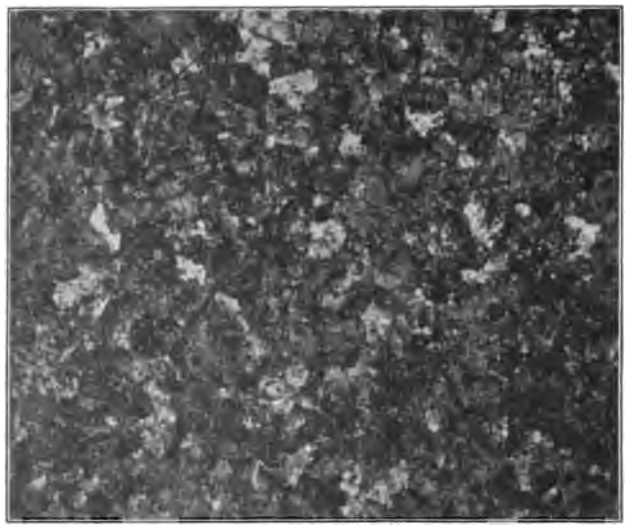
	Per cent.
C	.57
Mn	.65
Si	.167
S	.028
P	.012

AS RECEIVED. HOT ROLLED. BRINELL HARDNESS=240.

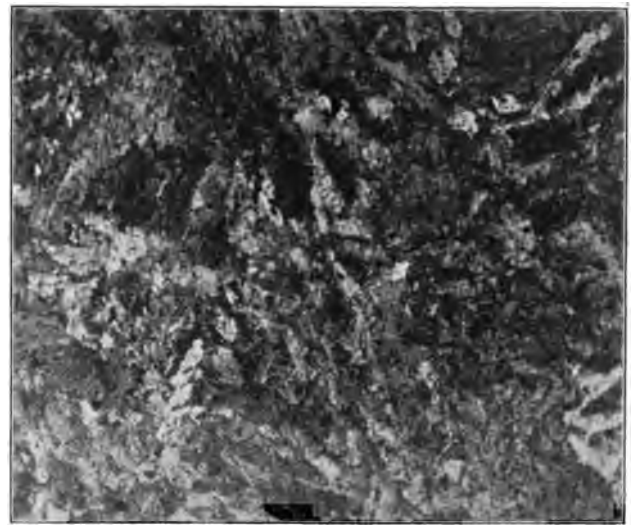


NORMALIZED. ANNEALED FROM 1,000° C. BRINELL HARDNESS=235.

	Per cent.
C	.71
Mn	.67
Si	.147
S	.035
P	.027

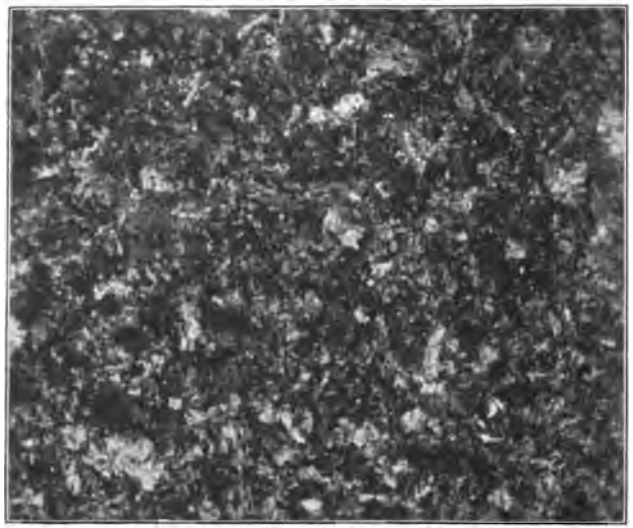


AS RECEIVED. HOT ROLLED. BRINELL HARDNESS=269.

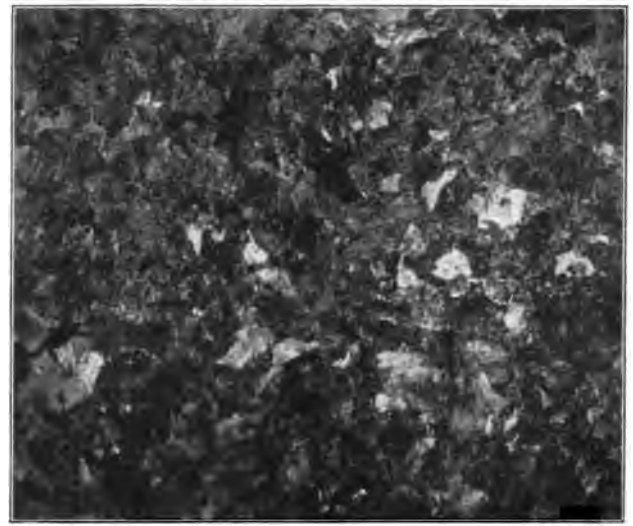


NORMALIZED. ANNEALED FROM 1,000° C. BRINELL HARDNESS=257.

	Per cent.
C	.83
Mn	.55
Si	.152
S	.028
P	.018

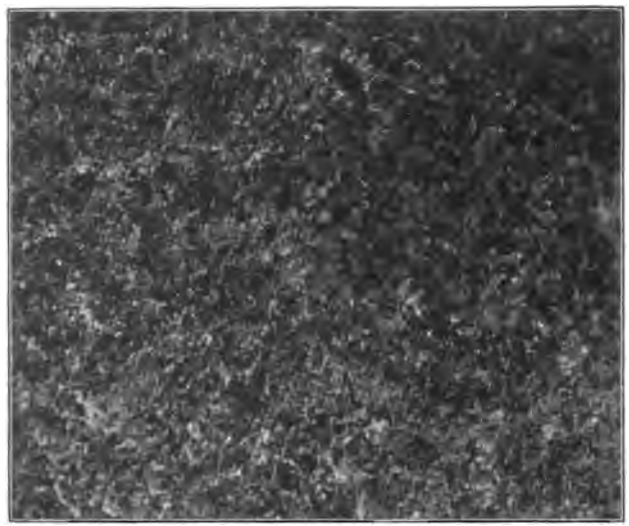


AS RECEIVED. HOT ROLLED. BRINELL HARDNESS=302.

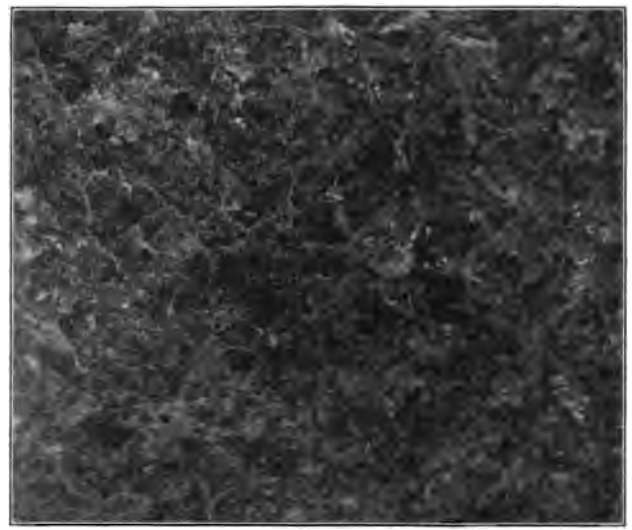


NORMALIZED. ANNEALED FROM 1,000° C. BRINELL HARDNESS=255.

	Per cent.
C	1.01
Mn	.39
Si	.160
S	.029
P	.016

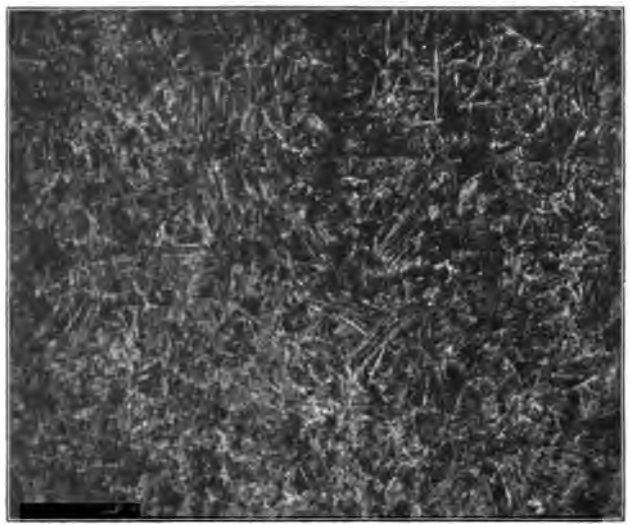


AS RECEIVED. HOT ROLLED. BRINELL HARDNESS = 238.

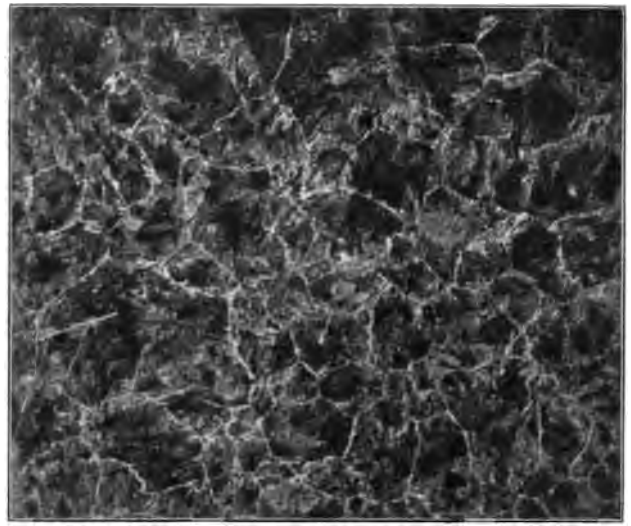


NORMALIZED. ANNEALED FROM 1,000° C. BRINELL HARDNESS = 269.

	Per cent.
C	1.22
Mn	.34
Si	.181
S	.031
P	.025

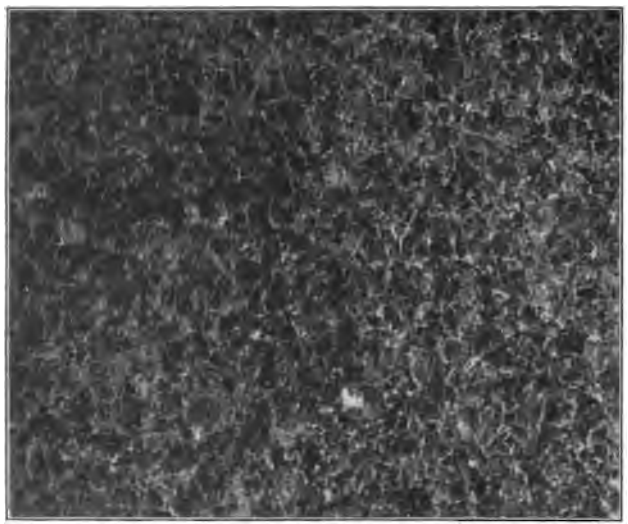


AS RECEIVED. HOT ROLLED. BRINELL HARDNESS = 321.

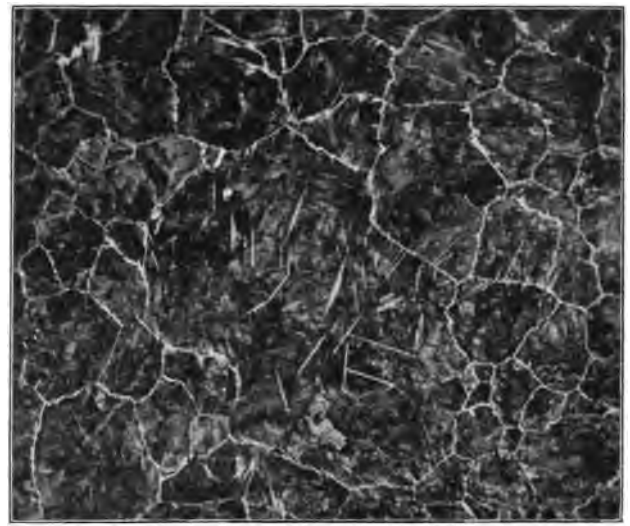


NORMALIZED. ANNEALED FROM 1,000° C. BRINELL HARDNESS = 255.

	Per cent.
C	1.39
Mn	.20
Si	.191
S	.029
P	.015



AS RECEIVED. HOT ROLLED. BRINELL HARDNESS = 351.



NORMALIZED. ANNEALED FROM 1,000° C. BRINELL HARDNESS = 302.

	Per cent.
C	1.46
Mn	.20
Si	.133
S	.035
P	.011
Cr	.35

were held at heat for one hour, for two hours, for three hours, etc., up till ten hours. Three pieces previously suitably marked were put in furnace and temperature raised as rapidly as possible to the desired point, where it was maintained for the specified length of time. At the end of this period one piece was quenched in oil, a second piece was allowed to cool in the air, and the third piece was allowed to remain in the furnace and cool with it, the furnace having been closed up again.

The hot junction of the thermocouple was inserted in a hole in the end of the furnace-cooled pieces. By means of a rheostat control on the furnace the desired temperature was maintained within plus or minus 10 degrees.

The oil-quenched pieces were subsequently all drawn at 600° C. for one-half hour and furnace cooled to facilitate machining.

One-quarter-inch disks for microscopic examination were cut from the ends of the treated bars. Likewise similar disks were cut from the ends of several bars before treatment for examination of the original structure.

The result of the static tensile, hardness, and Charpy impact tests are appended hereto.

As an additional experiment, one of the forged but untreated bars 1 inch round by 8 inches long was cut up into disks one-half inch long. These disks were treated with the larger bars and allowed to cool in the furnace. They were subsequently examined microscopically and Brinell hardness tests made. The object of this additional experiment was to start with pieces of the same grain structure, as some variation in grain size was noted between different samples of the original bars. The results of this additional experiment are appended.

CONSIDERATION OF RESULTS.

An examination of the test results from the furnace-cooled pieces (see Table 1) shows practically the same physical properties for all. The microstructures showed no consistent variation.

What has been said regarding the furnace-cooled pieces holds equally true for the air-chilled pieces. (See Table 2.) They are consistently somewhat stronger, both statically and dynamically, than the furnace cooled pieces and they are also harder, but among themselves they are quite consistent. In the case of the oil-quenched and drawn pieces the same uniformity holds true, except that the first five bars are slightly weaker and softer than the second five bars. This difference is due to the fact that in the drawing operation the first five bars were heated at one time and the second five bars were heated in a second run. The maximum temperature in the second run was undoubtedly slightly lower than in the first run.

The results given in Table No. 4 are Brinell hardness numbers and photomicrographs of the small sections cut from the same bar. These results show that the length of time of heating at just above Ac_1 has no influence on the hardness and very little on the grain size, though the intergranular ferrite seems to increase slightly in amount on the longer annealing heats.

CONCLUSION.

From these experiments we draw the conclusion that at temperatures slightly above Ac_1, the physical properties of the metal, both static and dynamic, and also the grain structure are not a function of the duration of the annealing operation. We believe, however, that for considerably higher temperatures the duration of heating would have an increased effect in promoting grain growth. Above the Ac_3 point the steel would be in the condition of a homogeneous solid solution, which would offer greater opportunity for grain growth upon holding at heat than exists below this point. In order to test this hypothesis it is proposed to continue a metallographic investigation along these lines, using annealing temperatures 20° and 100° above Ac_3.

From our results, however, we can say that for temperatures slightly above Ac_1 the grain size and physical properties are independent of the duration of annealing.

TABLE 1.—*Furnace cooled pieces.*

Test specimen No.	Heat treatment (760° C.).	Yield point (pounds per square inch).	Tensile strength (pounds per square inch).	Elongation (per cent).	Contraction (per cent).	Charpy impact (foot-pounds per square inch).	Brinell hardness No.
1 F....	1 hour.....	57,000	100,000	22.5	40.3	171.2	181
2 F....	2 hours....	55,500	97,500	20.0	30.7	172.5	176
3 F....	3 hours....	55,000	97,500	21.5	30.7	160.6	177
4 F....	4 hours....	53,000	99,500	22.5	40.3	144.7	181
5 F....	5 hours....	54,500	97,500	23.0	43.3	160.6	176
6 F....	6 hours....	55,500	99,000	25.0	30.7	167.5	171
7 F....	7 hours....	55,500	99,500	25.0	40.3	175.6	176
8 F....	8 hours....	54,500	98,000	20.0	24.0	167.8	175
9 F....	9 hours....	55,500	98,500	23.0	37.2	128.7	174
10 F....	10 hours...	55,500	98,000	23.0	40.3	147.5	173

TABLE 2.—*Air chilled pieces.*

Test specimen No.	Heat treatment (760° C.).	Yield point (pounds per square inch).	Tensile strength (pounds per square inch).	Elongation (per cent).	Contraction (per cent).	Charpy impact (foot-pounds per square inch).	Brinell hardness No.
1 A....	1 hour.....	63,000	106,500	24.0	46.2	182.7	194
2 A....	2 hours....	64,500	105,500	22.0	27.4	199.7	196
3 A....	3 hours....	67,500	106,000	22.0	46.2	160.5	200
4 A....	4 hours....	69,000	107,000	20.0	27.4	167.4	196
5 A....	5 hours....	67,000	106,500	23.5	34.0	184.1	196
6 A....	6 hours....	68,500	107,000	19.0	20.5	195.1	196
7 A....	7 hours....	69,000	107,000	20.0	30.7	188.2	196
8 A....	8 hours....	69,000	106,000	24.0	30.7	186.9	196
9 A....	9 hours....	69,500	107,000	21.5	30.7	185.7	199
10 A....	10 hours...	69,500	108,000	20.0	34.0	152.2	199

TABLE 3.—*Oil quenched and drawn pieces.*[1]

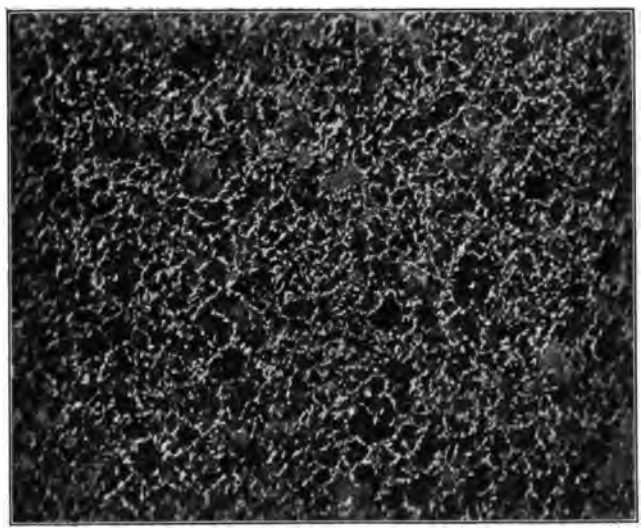
Test specimen No.	Heat treatment (760° C.).	Yield point (pounds per square inch).	Tensile strength (pounds per square inch).	Elongation (per cent).	Contraction (per cent).	Charpy impact (foot-pounds per square inch).	Brinell hardness No.
1 W...	1 hour.....	88,000	113,000	24.0	59.8	249.7	228
2 W...	2 hours....	87,500	114,500	21.5	57.2	312.5	225
3 W...	3 hours....	85,500	113,500	22.5	59.8	324.5	228
4 W...	4 hours....	88,000	114,000	21.5	54.6	305.7	222
5 W...	5 hours....	81,500	116,000	22.5	57.2	262.7	220
6 W...	6 hours....	87,500	120,500	21.0	54.6	218.8	233
7 W...	7 hours....	88,000	120,500	23.5	54.6	206.2	241
8 W...	8 hours....	88,000	119,000	22.5	57.2	190.7	238
9 W...	9 hours....	85,500	119,500	22.0	54.6	232.5	235
10 W...	10 hours...	85,500	120,500	20.0	51.9	220.5	234

[1] Oil quenched and drawn one-half hour at 600° C.

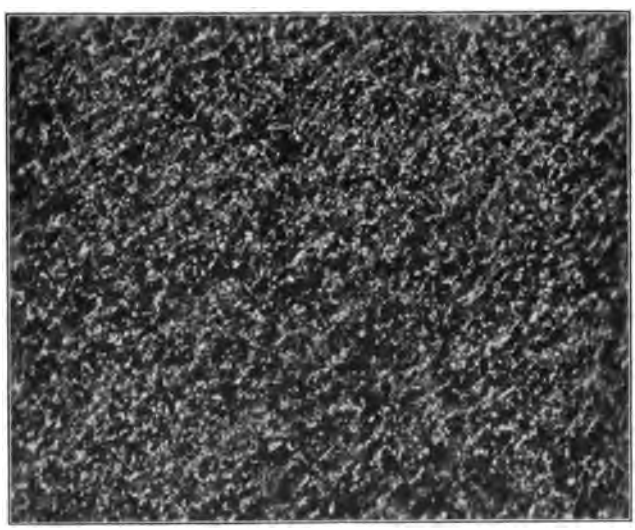
TABLE 4.—*Heat treatment and Brinell hardness numbers of sections taken from one bar.*

No.	Heat treatment (760° C.).	Brinell hardness No.	
0	Original bar.....	217	See photomicrograph No. 0.
1	1 hour.....	187	See photomicrograph No. 1.
2	2 hours.....	187	See photomicrograph No. 2.
3	3 hours.....	187	See photomicrograph No. 3.
4	4 hours.....	196	See photomicrograph No. 4.
5	5 hours.....	187	See photomicrograph No. 5.
6	6 hours.....	187	See photomicrograph No. 6.
7	7 hours.....	192	See photomicrograph No. 7.
8	8 hours.....	187	See photomicrograph No. 8.
9	9 hours.....	187	See photomicrograph No. 9.
10	10 hours.....	202	See photomicrograph No. 10.

The following micrographs represent these specimens.



NO. 0. (×75.)



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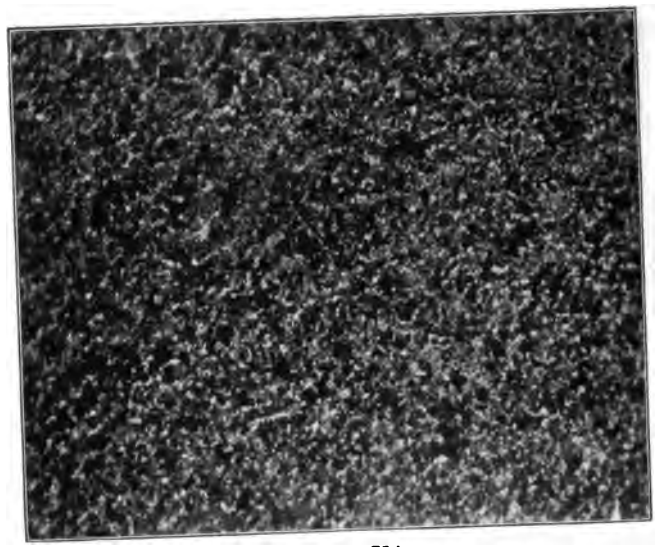

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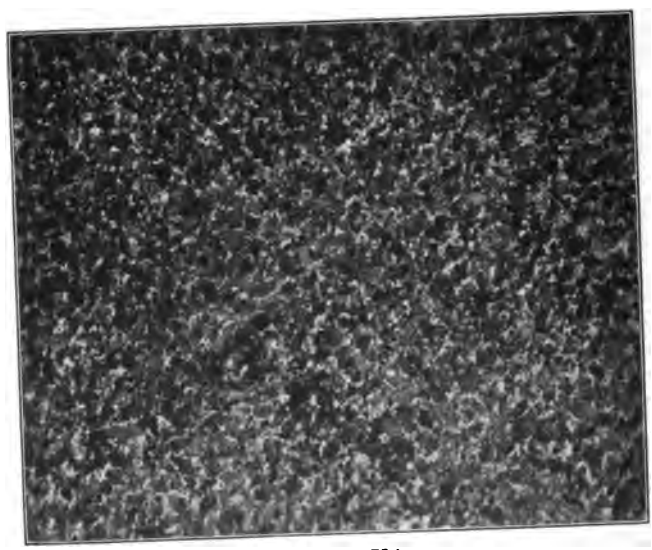

NO. 3. (X75.)

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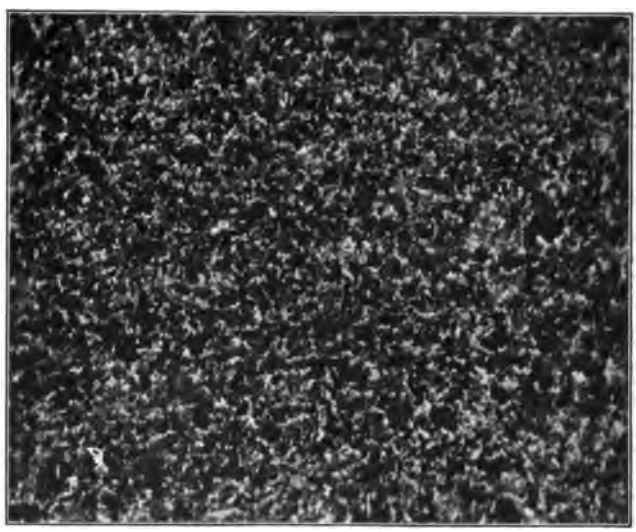

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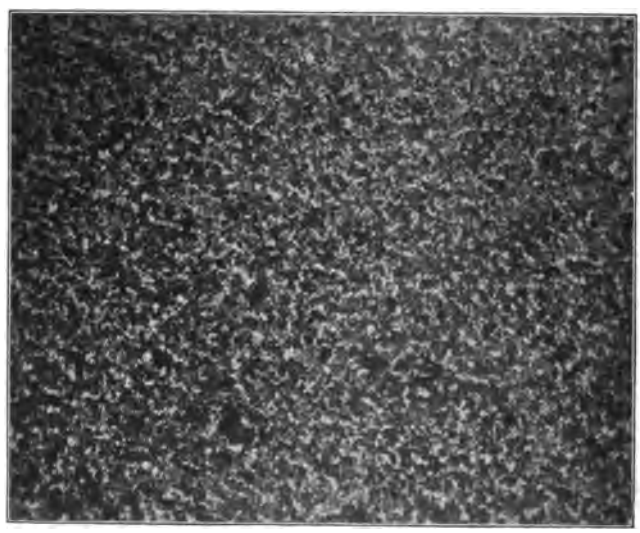

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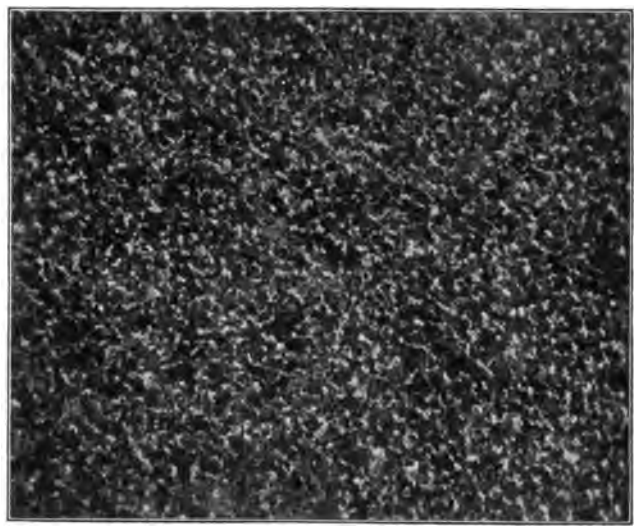

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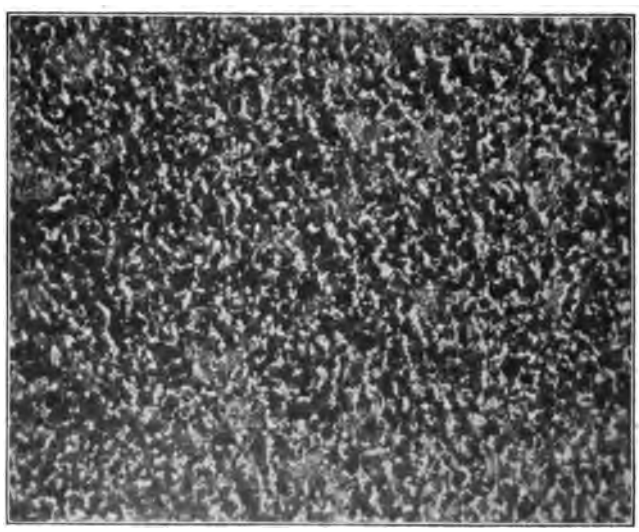

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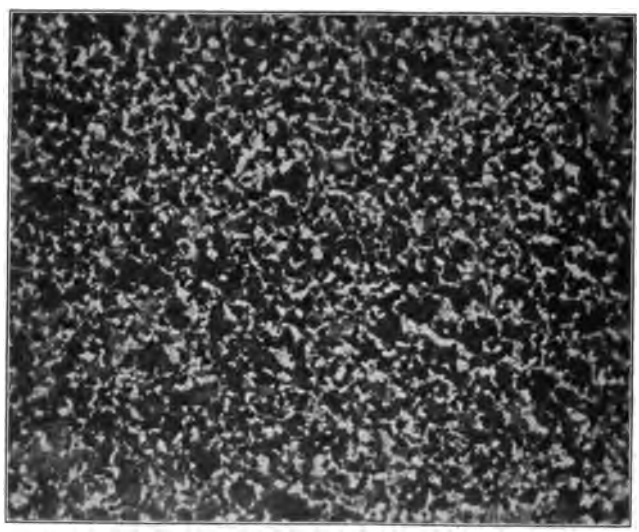


NO. 10. (×75.)

METALLOGRAPHIC EXAMINATIONS.

EXAMINATION OF SAMPLE OF A BROKEN 14-INCH SCREW BOX LINER.

OBJECT.

The object of this examination was to determine the quality of the metal, both physically and chemically.

DETAILS OF EXAMINATION.

The fragment of a 14-inch screw box liner which was received for examination was of approximately the following dimensions: 7 inches long by 5 inches wide by 3 inches thick. It was beveled and slightly curved at one end, and one side showed the original fracture. Photographs giving two views of the fragment were taken and are appended. Photograph No. 1 shows the original fracture, and photograph No. 2 shows one side and one end. The lines of radiation on the fractured surface show that the origin of the fracture was external to this fragment, and in the direction shown by the arrow on photograph No. 1. Three sides of the fragment were rough polished and etched for macrostructure with saturated alcoholic iodine solution. The metal etched very evenly, showing no trace of ingotism but a few small areas of minor segregation. These small areas were identified by means of sulphur prints and microexamination as areas containing more solid nonmetallic impurities than the main body of the metal.

The sulphur print reproduced in photograph No. 3 was taken on the freshly exposed surface when the fragment was split as hereinafter described. The darker spots are areas slightly higher in nonmetallic inclusions than the remainder of the metal. The area marked S was cut out, polished, and examined microscopically. It showed quite conclusively that this area contained more solid nonmetallic impurities than the main body of the material.

PHYSICAL TESTS.

No information was received as to how this fragment lay in the original screw box liner, so that the specimens taken could not with certainty be marked longitudinal, tangential, or radial. The fragment was split lengthwise of the piece and normal to the fracture, along the line AB (see photograph No. 1). From the larger portion four tension and ten Charpy impact specimens were taken as follows:

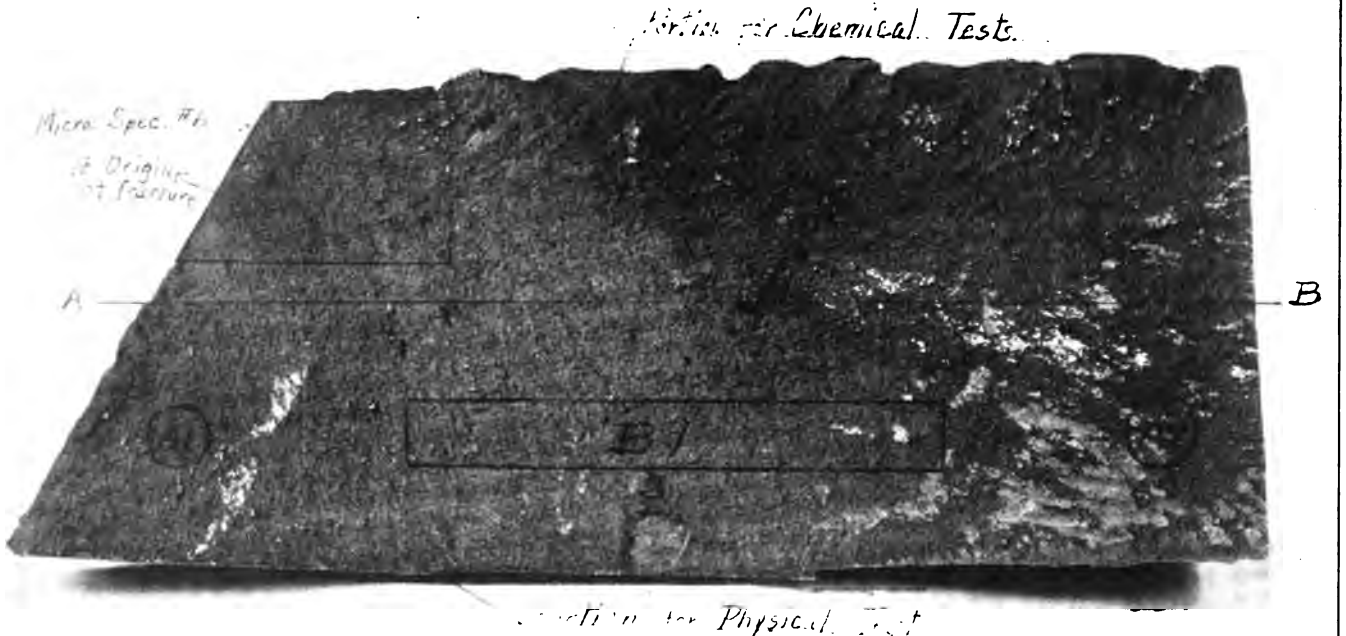
Specimen No. A 1 taken from the beveled end and normal to the fracture.

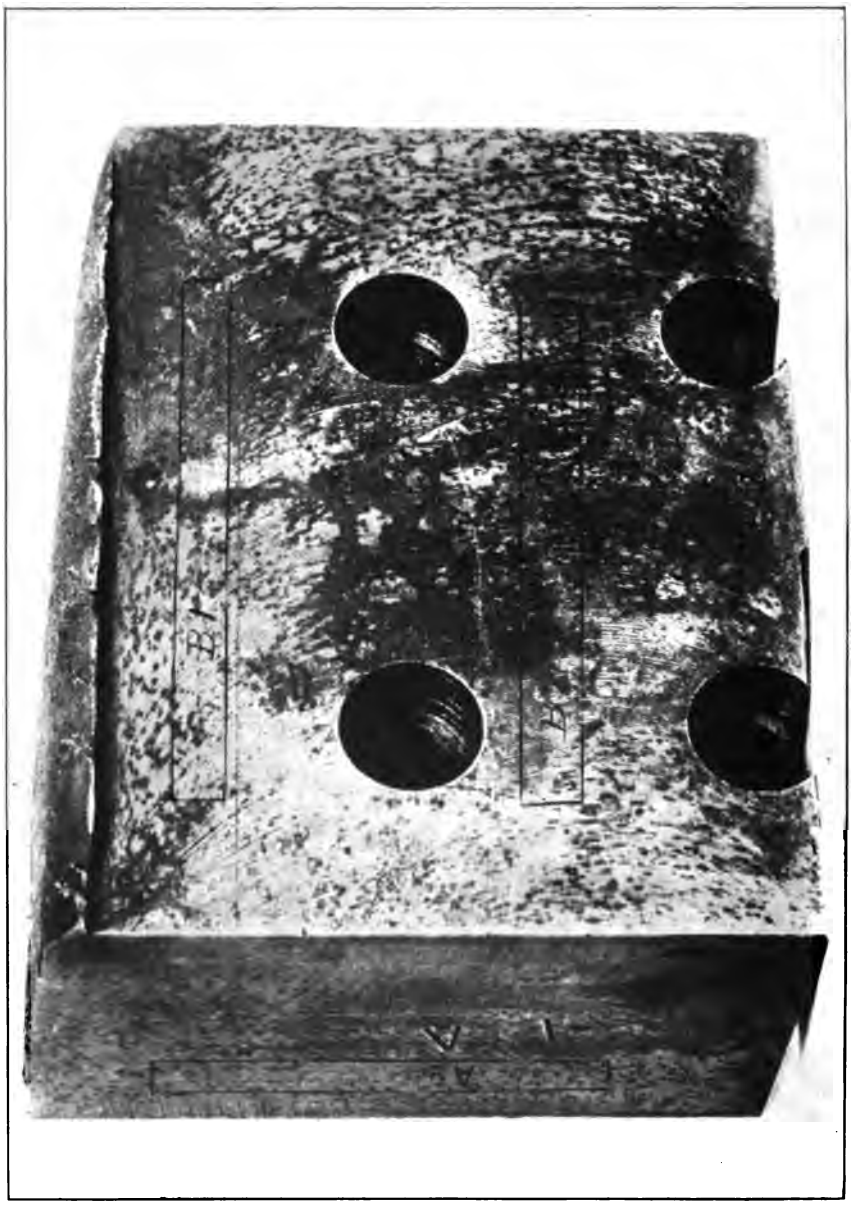
Specimen No. A 2 taken from the square end and normal to the fracture.

Specimen No. B 1 taken parallel to and near the fractured surface.

Specimen No. B 2 taken parallel to and as far as possible from the fracture.

PHOTOGRAPH NO. 1.





PHOTOGRAPH NO. 2.

Five Charpy impact specimens were taken parallel to the fracture and marked B; five were taken normal to the fracture and marked A. The results of the tests of these specimens are given in the following table:

Mark.	How taken out.	Yield point (pounds per square inch).	Tensile strength (pounds per square inch).	Elongation in 2 inches (per cent).	Contraction of area (per cent).	Brinell hardness No.	Charpy impact results (foot-pounds per square inch).		
							Maximum.	Minimum.	Average.
A 1..	Normal to fracture, beveled end.....	68,000	95,500	19.0	40.3	202	419.0	313.0	379.1
A 2..	Normal to fracture, square end.....	65,500	93,000	23.5	51.9	196			
B 1..	Parallel to and near fracture.....	66,000	93,500	18.5	34.0	196	417.5	285.5	371.3
B 2..	Parallel to and away from fracture.....	66,000	93,500	20.0	40.3	196			

An examination of the above table discloses that there is very little difference between any of the tests. The physical properties do not show a characteristic difference depending on the way the specimens were taken from the fragment. This fact tends to indicate that the metal has received very little forging. This deduction received confirmation from microscopic evidence which will be discussed later. Such differences as the above table does show lie in the figures for elongation and contraction of area, and indicate that the specimens near the fractured surface and near the origin of fracture were slightly less ductile than those taken farther away from the fracture. On the whole, however, the metal seems fairly uniform and the physical properties good. The Charpy impact figures are excellent for this class of material, and indicate good resistance to shock.

CHEMICAL TESTS.

Two samples for chemical analysis were taken from the smaller portion after the original fragment had been split. Sample No. 1 was taken near the fractured surface; sample No. 2 near the opposite surface and as far as possible from the fracture. Photograph No. 3 indicates these locations. The determined composition was as follows:

Sample.	C.	Mn.	Si.	S.	P.	Ni.	Cr.	Va.
	Per cent.	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*
No. 1.....	0.320	0.35	0.102	0.032	0.033	3.00	0 97	None.
No. 2.....	.316	.33	.102	.032	.033	3.00	.98	None.

These analyses show the composition to be normal for steel of this type, and reveal nothing as to the cause of fracture.

MICROSCOPIC TESTS.

The following seven specimens were examined microscopically:

1. One end of tension test specimen A 2.
2. One end of tension test specimen B 1.
3. One end of tension test specimen B 2.
4. One end of tension test specimen A 1.
5. The other end of tension test specimen A 1.
6. A section just under the fractured surface and near the point of origin of fracture. (Location shown on photograph No. 1.)
7. A section containing a spot which showed dark on the sulphur print. (Marked S on photograph No. 3.)

In general, microscopic examination showed the presence of an undesirable but not necessarily abnormal amount of solid nonmetallic impurities. These inclusions occurred throughout the material and were found slightly segregated; that is, in greater abundance in certain small areas. The inclusions consisted chiefly of silicates and sulphides. The fact that they were only elongated very slightly showed that the metal had not been forged to a great extent. The structure, which was nearly homogeneous sorbite with traces of ferrite, indicated that the piece had been satisfactorily heat treated.

Microscopic examination of the polished but unetched sections showed the presence of nonmetallic inclusions in amounts greater than desirable, but hardly abnormal for forgings as large as those used in gun construction. These inclusions were of two distinct colors, namely, dark slate or dove color, and very light gray. They occurred chiefly as rounded or very slightly elongated areas. The fact that they were not more elongated indicated that the material had not been forged to a great extent.

Micrograph No. 1, taken at 75 diameters, on the unetched surface, shows the occurrence of slag just under the fracture.

Micrographs No. 2 and No. 3, taken at 75 and 400 diameters, respectively, from test specimen No. A 1, show the greatest observed elongation of slag. Surface etched.

Micrograph No. 4, taken at 75 diameters from test specimen No. A 2, shows a light gray rounded slag spot. Surface etched.

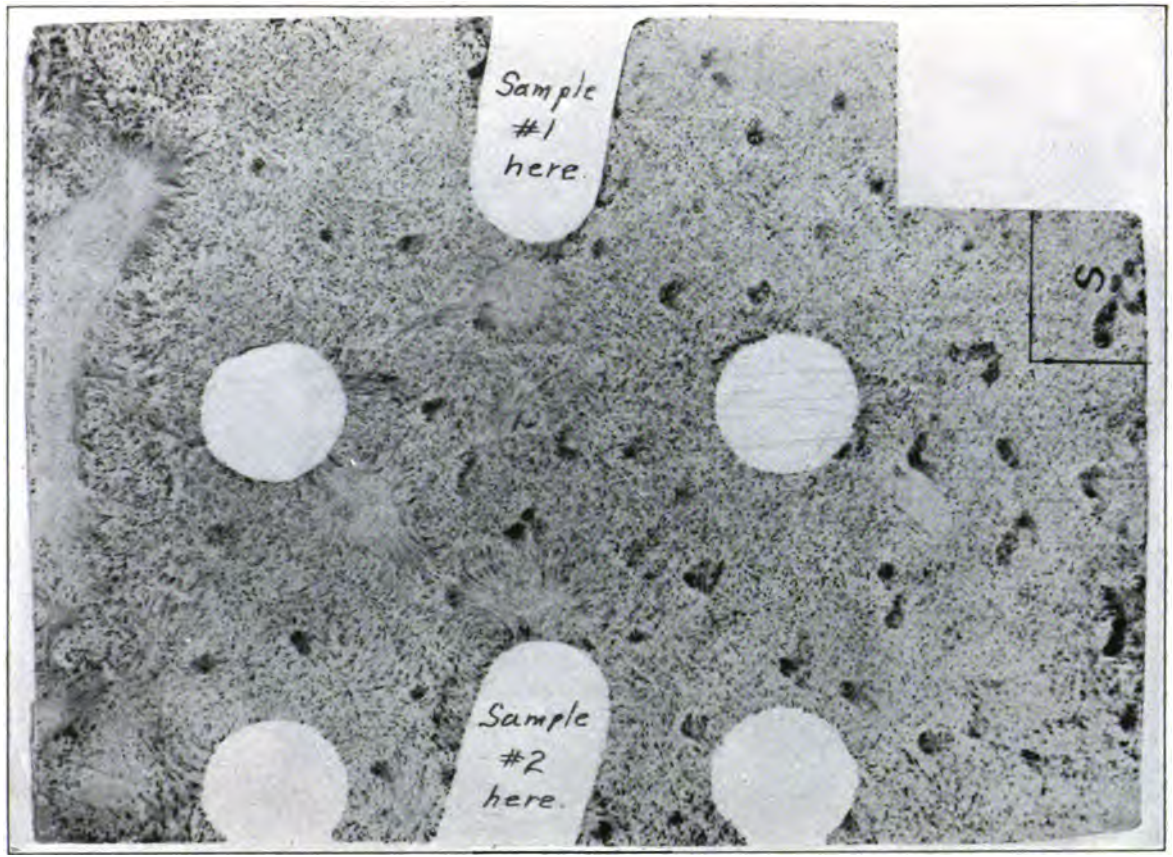
Micrograph No. 5, taken at 400 diameters from test specimen No. B 1, shows the structure of a slag inclusion. Surface etched.

The polished specimens were etched with a 4 per cent solution of nitric acid in amylic alcohol. The structure was found to be excellent, consisting of nearly homogeneous sorbite with traces of ferrite. This structure indicated that the heat treatment had been satisfactory. The character of the structure is shown in micrographs Nos. 2, 3, 4, and 5.

CONCLUSIONS.

From this report it is believed that the following conclusions can be drawn:

1. The quality of the metal is good.
2. The composition is a normal 3 to 1 nickel chrome steel.
3. The heat treatment and grain refinement are excellent.
4. The amount of slag, etc., is considered to be slightly greater than normal, but is not considered excessive.



PHOTOGRAPH NO. 3.

Reproduction of Sulphur Print showing where samples for chemical analysis and Section "S" for microscopic examination were taken.

MICROGRAPH NO. 1.

Section just under fracture, unetched, showing light gray slag. (X75.)

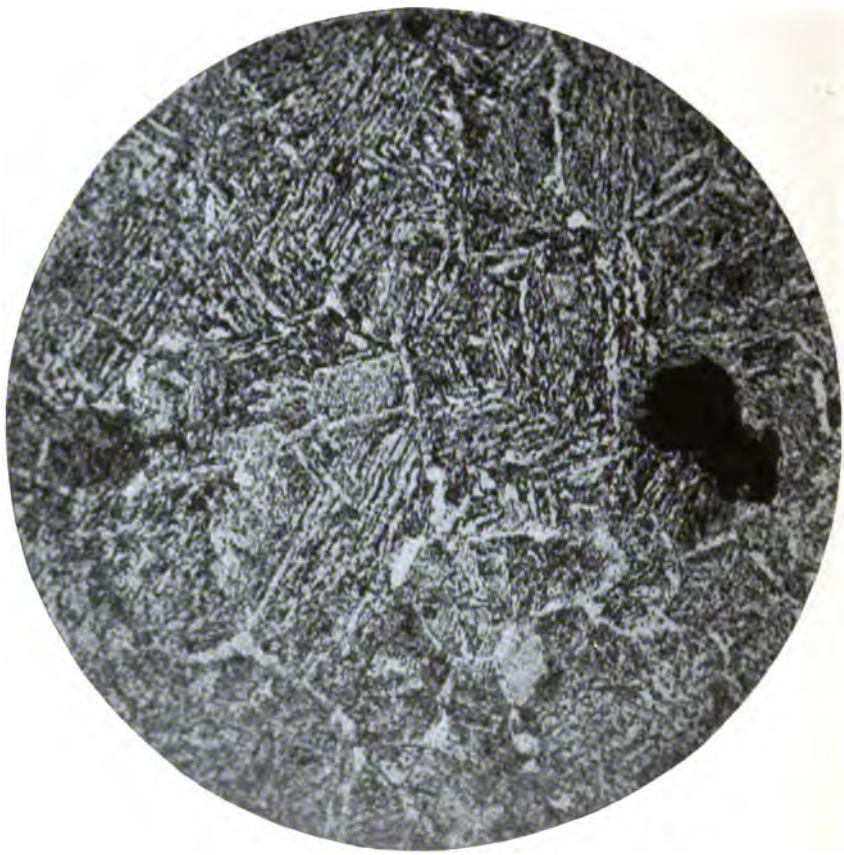
MICROGRAPH NO. 2.
Showing structure and elongated slag. Specimen A1. (X75.)

MICROGRAPH NO. 3.

Showing structure and elongated slag. (×400.) Specimen A1.

MICROGRAPH NO. 4.

Showing structure and light colored slag spot. (×75.) Specimen A2.



MICROGRAPH NO. 5.

Specimen B1. (×400.) Showing structure of a slag inclusion.

EXAMINATION OF FIRST FRAGMENT FROM JACKET OF 12-INCH GUN, NO. 58, MODEL 1905. BURST AT PROVING GROUND BY EXCESSIVE PRESSURE.

The section taken for examination was chosen because it seemed to show a fairly well defined center of radiation indicating the probable origin of fracture. Photograph No. 1 shows the nature of the fractured section removed for test.

Six tensile specimens were machined from the fragment, and when tested showed the following results:

Marks.	Yield point (pounds per square inch).	Tensile strength (pounds per square inch).	Elongation (per cent).	Contraction (per cent).	Appearance of fracture.	Charpy impact test (foot-pounds per square inch).	Brinell ball hardness.
L	.....	21,500	None.	None.	Granular; fractured diagonally at end of stem through thread.	[1] 344.5	196
L	.....	34,000	None.	None.	.....do.....		
T	52,000	99,500	21.5	40.3	Silky.....	[1] 210.9	196
T	51,500	98,500	22.0	40.3	.....do.....		
R	51,500	99,500	13.5	20.5	Fine granular.....		
R	52,000	99,500	14.5	27.4	Fine granular, 70 per cent; amorphous, 30 per cent.	[1] 284.1	196

[1] Average of four tests.

The results obtained with the two longitudinal specimens were unsatisfactory, due to the fact that fine cracks developed which caused the specimens to fracture at end of stem, through the thread. These cracks are believed to have originated at the fractured surface at the time the gun burst. The tangential and radial strengths were very uniform. The Charpy impact test measures the brittleness of the metal, and the results obtained indicate satisfactory material.

For microscopic examination a piece approximately 4 inches cubical was cut out, rough polished on three sides, and etched with iodine solution. The etched specimen is shown in photograph No. 2. The etching disclosed a certain amount of ingot structure which had not been removed by the forging or heat treatment to which the piece had been subjected. The ingot structure is always undesirable, as it shows imperfect heat treatment, and this is confirmed in the microscopic examination. Unfortunately the ingot structure is not shown in the photograph, but is very evident to the eye. The amount of slag and segregation shown up by this process was practically normal, and there was no evidence produced which would indicate a cause of fracture.

For microscopic examination, cross sections of each of the six test specimens, two each from longitudinal, tangential, and radial posi-

tions, were used. The amount of slag was normal in each. The structure, however, is coarse in all and indicates imperfect heat treatment. The mass of metal is large, and a fairly coarse structure might be expected, but there is distinct evidence of slow and undisturbed cooling from a high temperature. The failure to wipe out the original structure by forging or heat treatment is shown in photograph No. 5, where many of the individual grains show crystallization within the grain. This is shown in those grains where light and dark areas appear within the same grain, the difference of color being due to the difference of orientation of the individual crystals making up the grain.

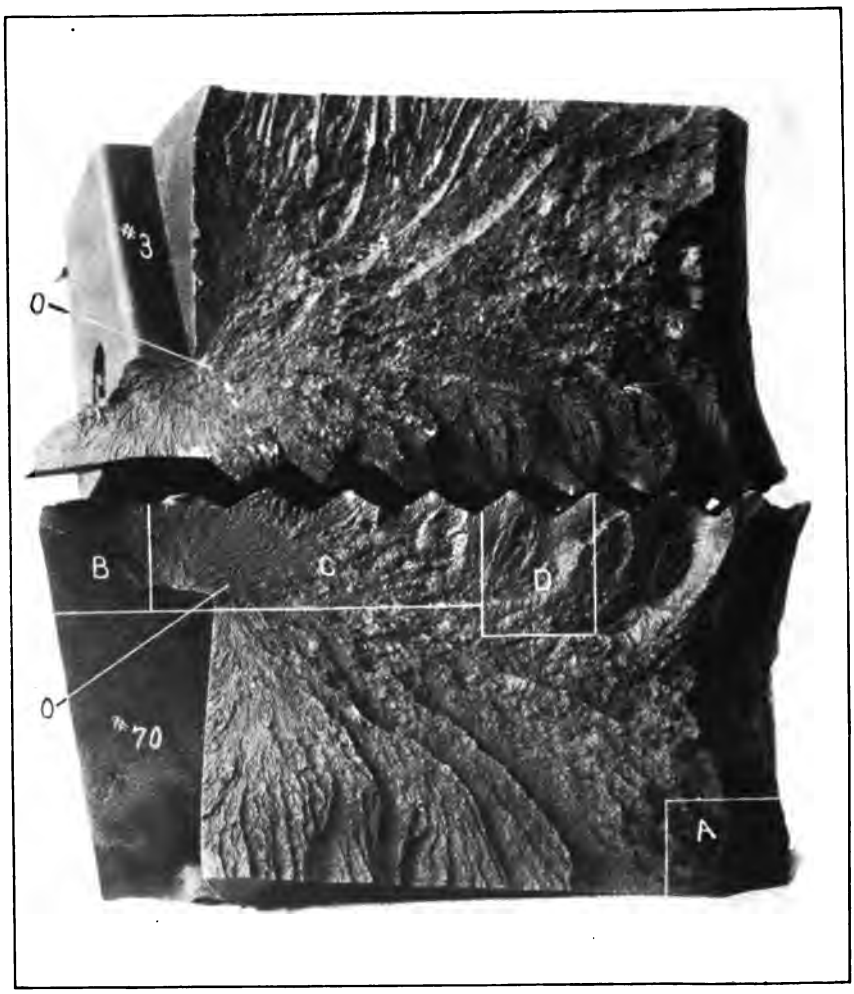
While there is distinct ingot structure and coarse microstructure in this material, both indicating unsatisfactory heat treatment, it can not be said to be the cause of the failure. The coarse structure may be considered as a contributing cause.

PHOTOGRAPH NO. 1.

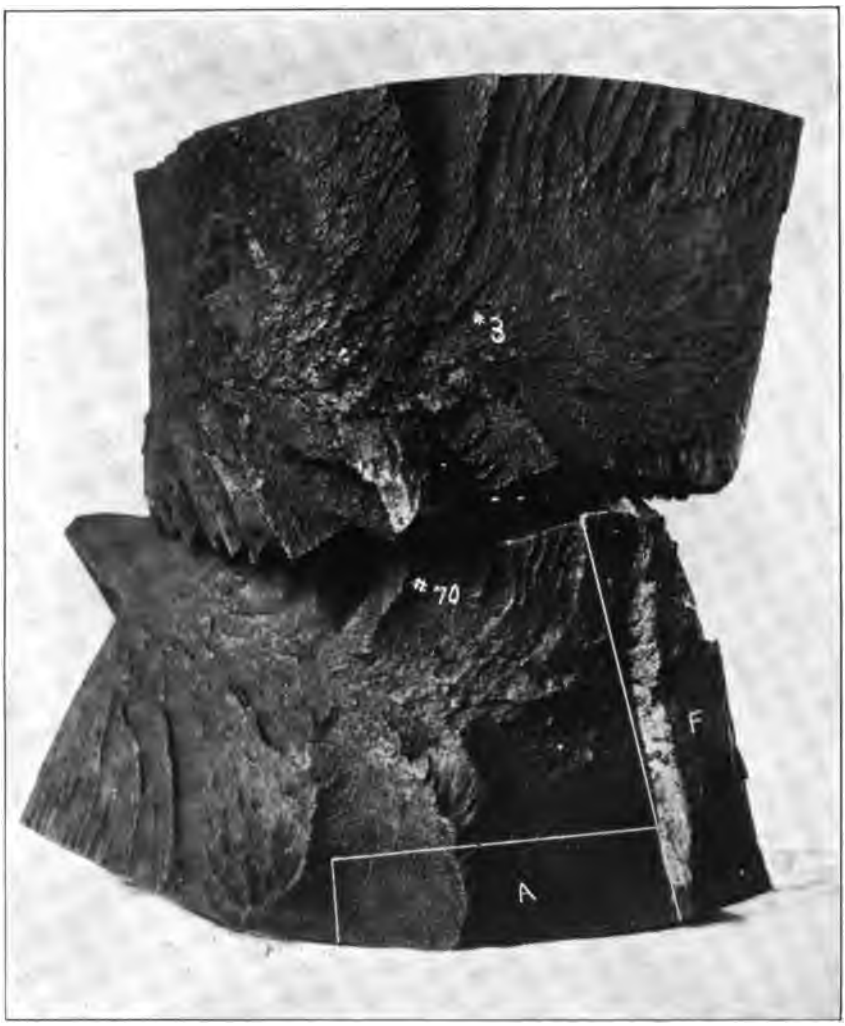
PHOTOGRAPH NO. 2.

PHOTOGRAPH NO. 5. (×75.)

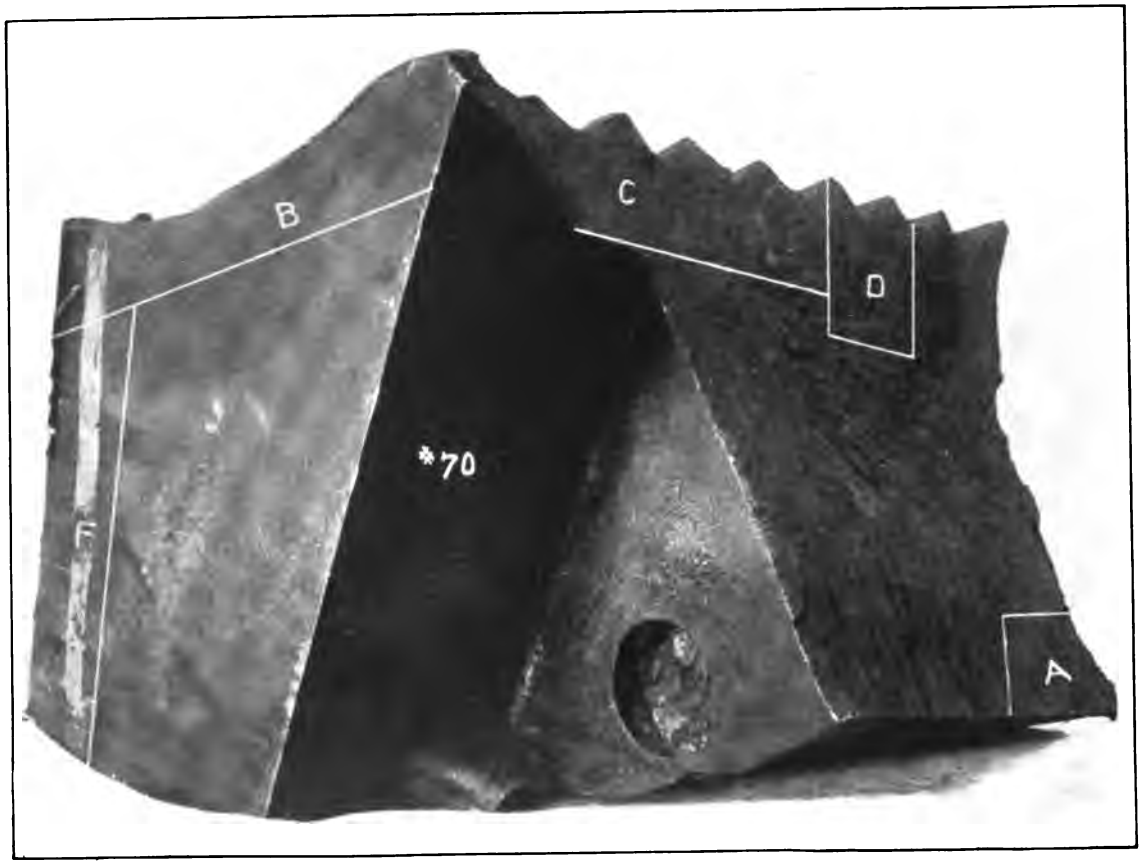
Tangential test piece, 12-inch gun jacket. Specimen B1, showing light and dark centers in same grain.



PHOTOGRAPH NO. 1.



PHOTOGRAPH NO. 2.



PHOTOGRAPH NO. 3.

EXAMINATION OF TWO ADDITIONAL FRAGMENTS FROM THE JACKET OF 12-INCH GUN NO. 58.

OBJECT.

The object of this examination was to investigate further the character of the metal from a burst jacket of a 12-inch gun No. 58, the samples for test being taken nearer the origin of fracture than in the previous sample examined.

INTRODUCTORY.

Two fragments of the above jacket were received, marked No. 3 and No. 70.

PROCEDURE.

Three photographs, Nos. 1, 2, and 3, were taken of these fragments, showing the fractured surfaces. Photograph No. 1 shows the fractured surfaces on each fragment which extended parallel to the bore of the gun. The point marked *O* has the appearance of being an origin of fracture, and will be referred to as such hereinafter. Photograph No. 2 shows the fractured surface which extended nearly normal to the bore of the gun. Photograph No. 3 shows the breech end and a portion of the fractured surface of fragment No. 70.

PHOTOGRAPH NO. 3.

Six tensile test specimens were machined from fragment No. 70. Their locations are shown in white in photographs Nos. 1, 2, and 3. The results of the tests of these six specimens are given in the following table:

Mark.	Yield point (pounds per square inch).	Tensile strength (pounds per square inch).	Elongation (per cent).	Contraction (per cent).	Appearance of fracture.	Brinell hardness No.
A.....	51,000	96,500	25.0	40.3	Fine granular, 50 per cent; dull silky, 50 per cent.	187
B.....	51,240	96,510	20.5	24.3	Fine granular with dull silky spot at circumference.	187
C.....	49,500	96,500	25.5	49.1	Dull silky.....	187
D.....	48,500	95,500	20.0	30.7	Fine granular, silky spot at circumference.	187
E.....	47,260	94,520	14.0	17.4	Fine granular.....	192
F.....	49,500	96,500	19.0	27.4	Fine granular, 85 per cent; amorphous, 15 per cent.	183

HOW TAKEN OUT.

A. Tangential. Outside.
B. Tangential. Inside, near origin of fracture.
C. Longitudinal. Inside, near origin of fracture.
D. Tangential. Inside.
E. Radial.
F. Radial.

The specified tensile requirements for this material are:

Elastic limit, 48,000 pounds per square inch.
Tensile strength, 88,000 pounds per square inch.
Elongation in 2 inches, not less than 18 per cent.
Contraction of area, not less than 30 per cent.

It will be noted that the specimen E falls below these requirements as to elastic limit, elongation, and contraction, while specimens B and F fail to meet the contraction requirements. Specimens E and F, however, are radial tests, and specimen B is an inside tangential test located near the probable origin of fracture. On the whole, the physical tests were satisfactory, and the material would hardly be rejected because of these results.

Two slabs were cut from fragment No. 3 parallel to the two fractured surfaces. These slabs were polished and etched macroscopically. Photograph No. 4 shows the result of etching one surface with tincture of iodine. This surface was parallel to the bore of the gun. Two effects will be observed as a result of this etching.

(1) Pronounced ingotism is made evident by the development of interlacing needles which show black in the picture.

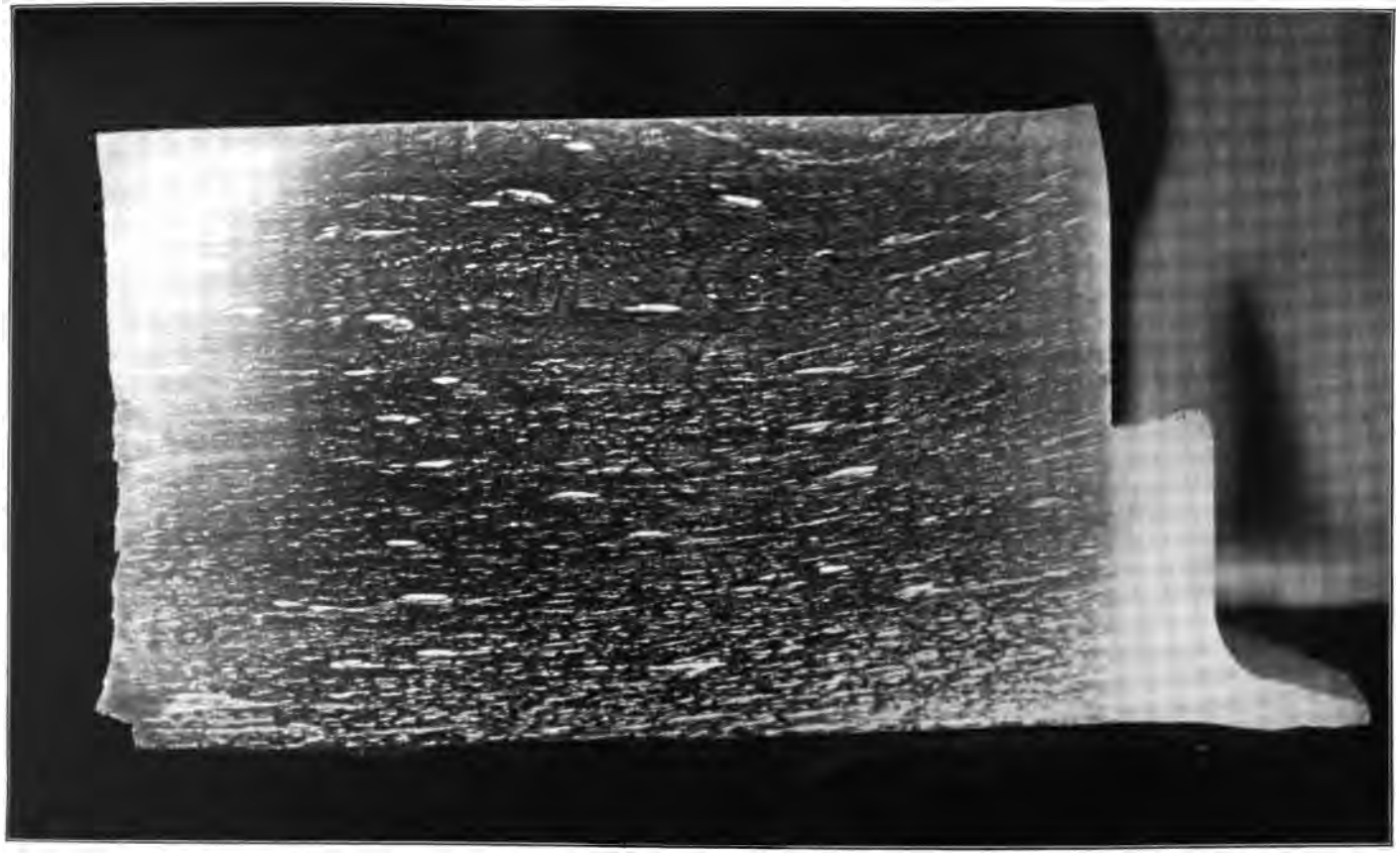
(2) Nonuniformity is shown by the development of elongated areas and streaks which show white in the picture.

Photograph No. 5 shows the same slab as No. 4 after repolishing and etching with copper ammonium chloride. The same characteristics are brought out by this reagent, except that the pattern is reversed. In this case the interlacing needles are white while the elongated spots are dark. Photograph No. 6 is the reproduction of a sulphur print of the same slab as shown in photographs Nos. 4 and 5. This picture is a mirror image of the two previous ones, but it will readily be seen that the elongated spots are discernable as darker areas than the rest of the picture. (The white spot and the blurs have no significance in this picture.) From these facts it may be stated that the "elongated areas" are areas of nonhomogeneity and probably contain slightly more sulphur and perhaps more phosphorus than the main portion of the metal. The segregations are not, however, believed to be of a nature as to impair seriously the quality of the metal.

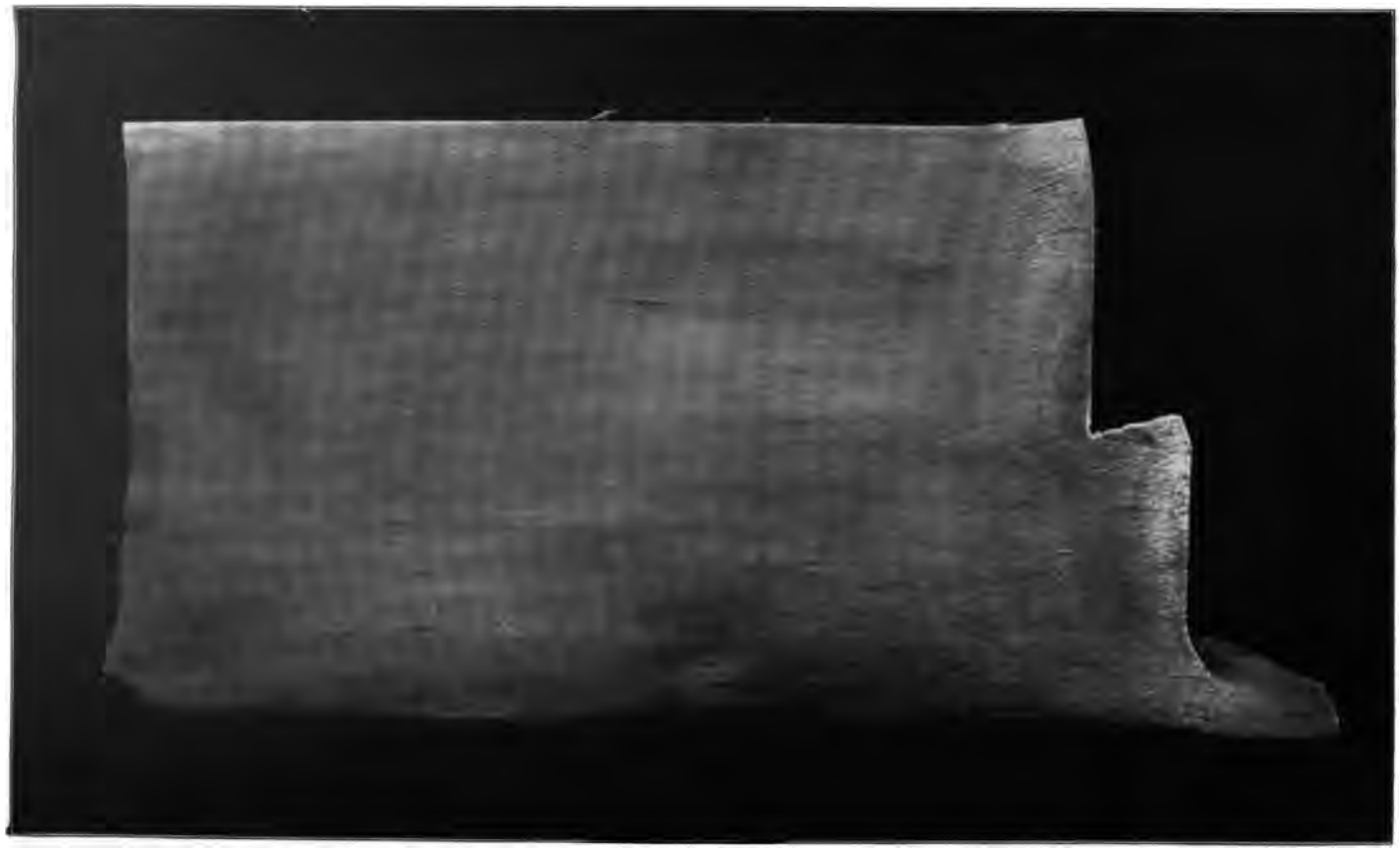
Microexamination was made on the threaded ends of the six tensile test specimens, and the following observations were made. Slag in elongated globules was present in considerable though not necessarily harmful amounts. This slag seemed to be somewhat more abundant in the portions near the origin of fracture "O." Elongated slag globules generally occurred in the areas which etched light with iodine solution. Photomicrographs Nos. 7 and 8 show the characteristic appearance of this slag on the unetched surface. The crystalline structure which became evident upon etching was rather coarse, and indicative of imperfect heat treatment, though very great grain refinement is not to be expected in masses of metal of this size. The characteristic structure is shown by photomicrographs Nos. 9 and 10. No. 9 shows the same area as photomicrograph No. 7.

Chemical analysis for carbon and phosphorus of this material gave the following results:

	Per cent.
Carbon	.48
Phosphorus	.023



PHOTOGRAPH NO. 4.

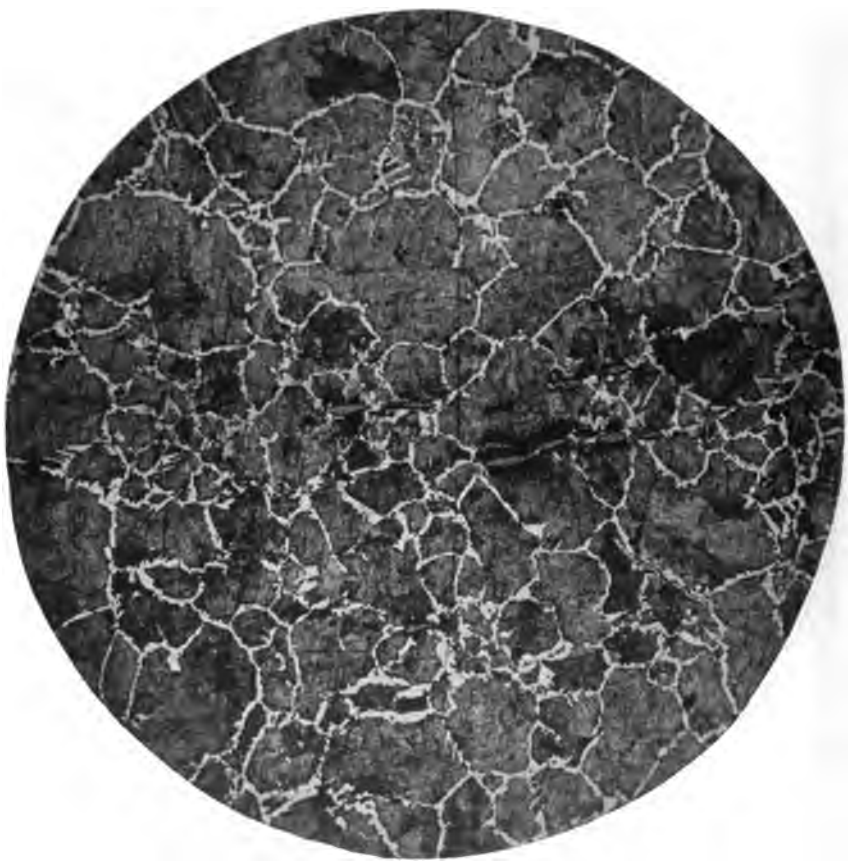


PHOTOGRAPH NO. 5.

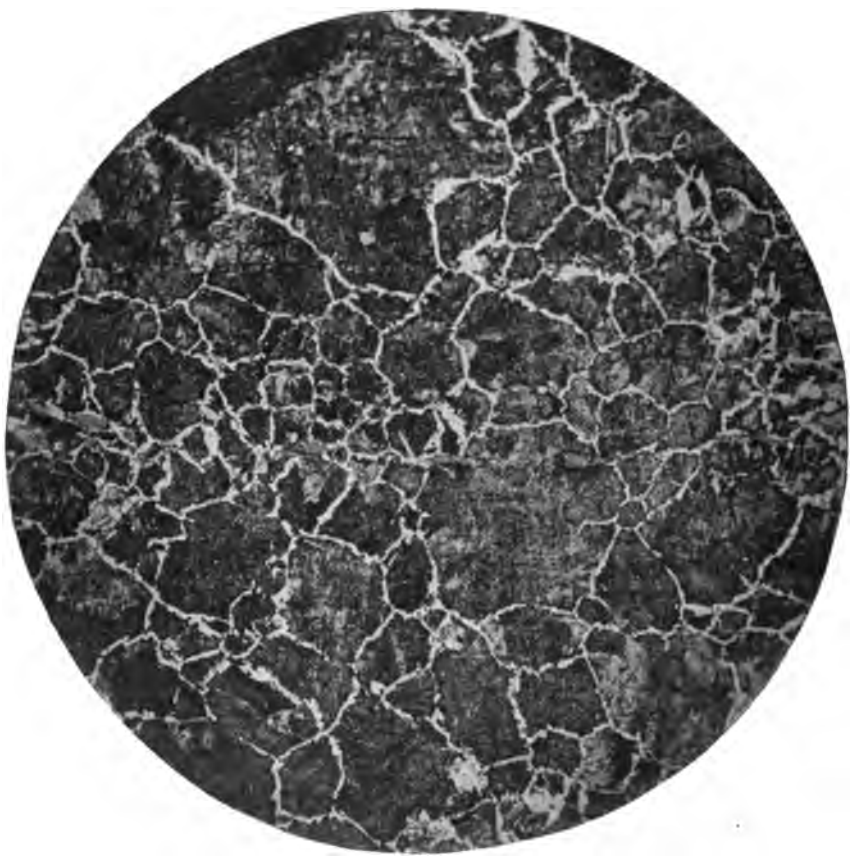
PHOTOGRAPH NO. 6.

PHOTOGRAPH NO. 7. (×75.)

PHOTOGRAPH NO. 8. (X75.)



PHOTOGRAPH NO. 9. (X75.)



PHOTOGRAPH NO. 10. (X75.)

CONCLUSIONS.

As a result of this investigation, the following conclusions can be drawn.

1. The metal has not been forged enough to put it in its best condition. Ingotism has not been entirely removed. Tangential and longitudinal test specimens, however, meet the physical specifications, except in the case of specimen B, which falls slightly below on contraction of area.

2. The heat treatment has not been of the best; that is, the coarse crystallization is indicative of the metal having been subjected to too high a temperature.

3. Heterogeneous areas which generally contain elongated slag globules, and which seem to be somewhat richer in sulphur and possibly phosphorus, are scattered irregularly throughout the material. These areas seem to be elongated parallel to the bore of the gun. Also, they appear to be in somewhat greater abundance near the point of origin of fracture "O."

4. None of these conditions may be definitely assigned as the cause of failure, but it is believed that they may have all been contributory.

EXAMINATION OF METAL FROM A 3-INCH FIELD GUN TUBE.

This tube was manufactured at Watervliet Arsenal from purchased forgings and came under suspicion through excessive shrinkage sets.

OBJECT.

The object of this examination was to determine if there was any defect with this material of a chemical or physical nature.

INTRODUCTORY.

The broken ends of two tensile test specimens from a 3-inch field gun tube were received. These specimens, No. 1 and No. 2, were taken from the muzzle end of the forging in a tangential direction.

PROCEDURE AND DISCUSSION.

Elongation and contraction measurements were made on these specimens to check up the figures given in the correspondence. These figures were found to be correct.

The metal from test specimen No. 1 was taken for experimental purposes.

Brinell hardness tests made in three places showed the hardness to be uniformly 153.

Chemical analysis showed the composition of this material to be as follows:

	Per cent.
Carbon	0.30
Manganese	.77
Sulphur	.020
Phosphorus	.015
Nickel	3.50
Chromium	.25

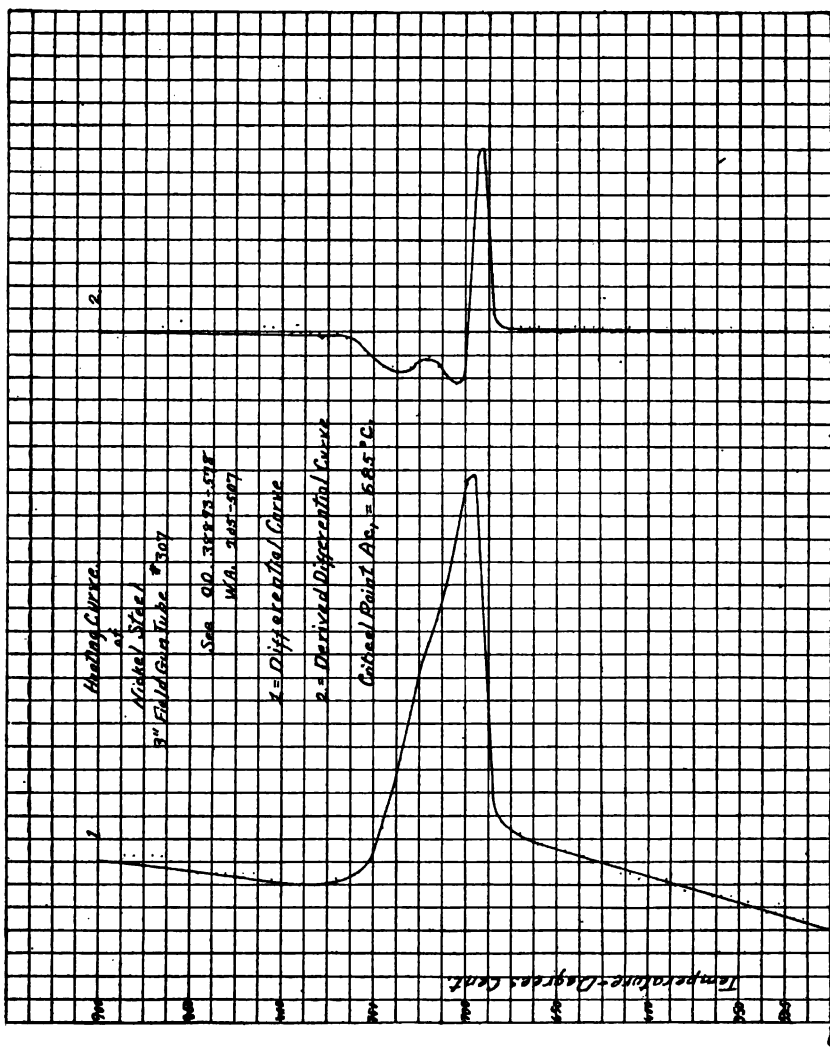
Microscopic examination showed the material to be nonhomogeneous and full of streaks. These streaks extend across the diameter of the test specimen, and are parallel to the laminations visible in the fracture. The streaks extend along the direction of forging of the metal, and in some cases elongated threads of slag are visible. The dark bands have a sorbitic structure which is the most desirable structure for gun forgings. The light bands are similar as to grain structure, but seem either to contain less carbon or to have it held more completely in solid solution. The cause for this streakiness has not been definitely determined, other than that the elongation of the streaks is undoubtedly due to forging. The nonhomogeneity is possibly caused by incomplete diffusion of the nickel and the explanation is offered that the light streaks are probably rich in

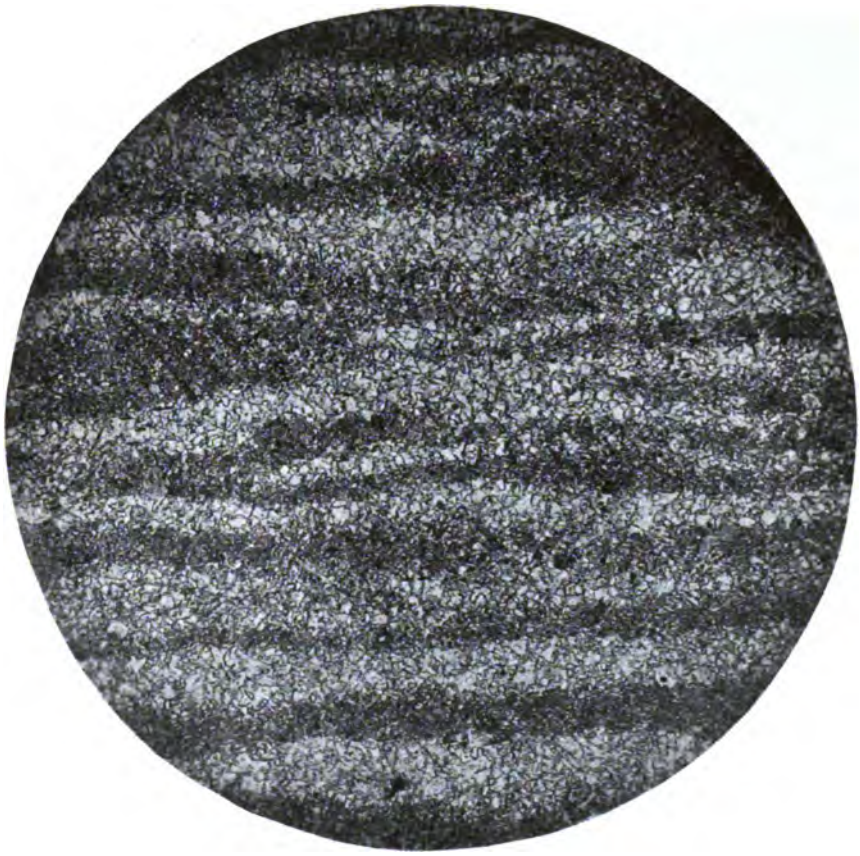
nickel as compared to the dark areas. Micrograph No. 1 (75 diameters) shows the streakiness of this material along the direction of forging. Micrograph No. 2 (75 diameters) shows a cross section of the streaks. Micrograph No. 3 (400 diameters) shows the structure of both the light and dark portions of the material at a higher magnification. Micrograph No. 4 (250 diameters) shows an elongated thread of slag which undoubtedly acted to lower the ductility of the material in a tangential direction.

Heating and cooling curves taken on this material by the differential method showed the Ac_1 point to be at 685° C., and the Ar_1 point to be at 580° C. See plates, pp. 240 and 241. These critical points occur at the temperatures which might be expected for material of this composition.

CONCLUSIONS.

1. The chemical composition of this material is normal for a 3½ per cent nickel steel, except for 0.25 per cent of chromium. This amount of chromium, however, should not affect the material to its detriment.
2. The critical points on heating and cooling are normal for this material.
3. The structure was found to be nonhomogeneous and streaky, though the cause for the nonhomogeneity is not definitely determined.
4. Some elongated slag lines were found though not to an abnormal extent.


Heating Curve of Nickel Steel 3" Field Gun Tube #307
Sea 90. 3573.57K W.A. 305-307
1 = Differential Curve
2 = Derived Differential Curve
Critical Point Ac1 = 685°C.
Temperature-Degrees Cent.

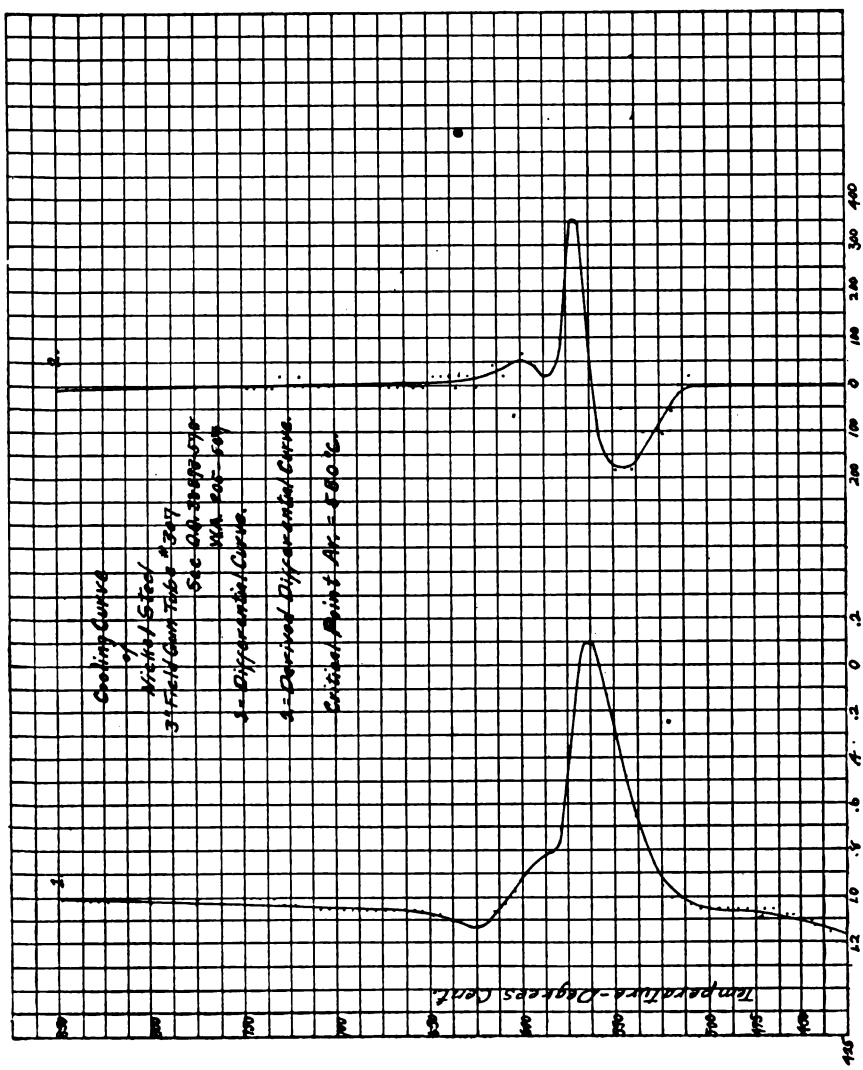


MICROGRAPH NO. 1. (X75.)

MICROGRAPH NO. 2. (X75.)

MICROGRAPH NO. 3. (×400.)

MICROGRAPH NO. 4. (X250.)


Cooling Curve
of
Nickel Steel
3½ Field Gun Tube #347
Sec. 04-3880-07C
W.A. 20E-69
1-Differential Curve.
1-Derived Differential Curve.
Critical Point Ar. = 680°C.
Temperature - Degrees Cent.

EXAMINATION OF A BROKEN AXLE BRACKET CAP.

OBJECT.

This investigation was made to determine the quality of metal in a broken axle bracket cap, supposedly of cast steel No. 2.

INTRODUCTORY.

During the ordinary course of assembly in the carriage, one lug was broken off by hand, indicating poor physical condition of the metal.

INVESTIGATIONS.

The appearance of the fracture was flaky, coarsely crystalline, and typical of unannealed cast steel. Along one side and two ends of the fracture was the characteristic appearance indicative of surface decarbonization. The edge which did not show this effect had been machined.

The fractured end was polished and etched. Photograph No. 1, which is magnified about four times, shows the appearance of the etched surface. The decarbonized edge is readily seen as a black band, and the ferrite crystal boundaries are also readily seen, showing as black lines in the picture. It will be noted that these lines lie approximately normal to the surface of the casting. The circular impression near one end is the result of a Brinell hardness test.

Microscopic examination showed the material to be normal as to the amount of slag. The structure is typical of cast steel, consisting of large grains of sorbito-pearlite with ferrite boundaries. Needles of ferrite also penetrate the pearlite grains. This structure is shown in micrograph No. 3. The white is ferrite and corresponds to the dark lines in photograph No. 1. Micrograph No. 2 shows the appearance of the decarbonized edge.

Tensile, Charpy impact, and Brinell hardness tests made on this material gave the following results:

Yield point, pounds	50,700
Tensile strength, pounds	99,400
Elongation, per cent	6.5
Contraction, per cent	6.4
Charpy test, foot-pounds per square inch	16.6
Brinell hardness No	172

Required for cast steel No. 2:

Elastic limit, pounds	35,000
Tensile strength, pounds	75,000
Elongation, per cent	15
Contraction, per cent	20

It will be seen that these figures do not meet the ductility requirements for cast steel No. 2. The resistance to shock is extremely low.

Chemical analysis showed the composition to be as follows:

Carbon	0.48
Manganese	.64
Silicon	.278
Sulphur	.051
Phosphorus	.031

This composition is satisfactory except that the carbon is somewhat higher than recommended for cast steel No. 2 in Ordnance Pamphlet No. 434.

In order to determine what the structure of this material would have been if it had been properly heat treated, a small specimen was given the following heat treatment in an experimental electric furnace which simulated foundry annealing conditions: Heated to 900° C., held 30 minutes, cooled in the furnace at a slightly accelerated rate. Reheated to 500° C. and furnace cooled. Photomicrograph No. 4 shows the structure after this treatment. It is a very good example of the refinement caused by proper annealing of cast steel.

CONCLUSIONS.

The difficulty with this material, and the cause for the breakage of the piece, is that the casting was not annealed. If it had been given the regular deingotizing and toughening treatment, it would have been put in condition for satisfactory service. The decarbonized surface noted is characteristic of all steel castings, and the rather high carbon content would not prevent the material from meeting the prescribed physical requirements.

EXAMINATION OF ALUMINUM BRONZE.

OBJECT.

The object of this investigation was to determine the chemical composition and physical properties of commercial aluminum bronze.

Two cast bars 1½ inches diameter by 6 inches long and a sample cast gear blank were received from open market. The two bars were machined into tensile test specimens and tested with the following results:

Marks.	Tensile strength (pounds per sq. in.).	Elongation (per cent).	Contraction of area (per cent).	Brinell hardness No.
No 1...	79,200	32.5	29.5	144
No 2...	78,000	29.5	29.5	144

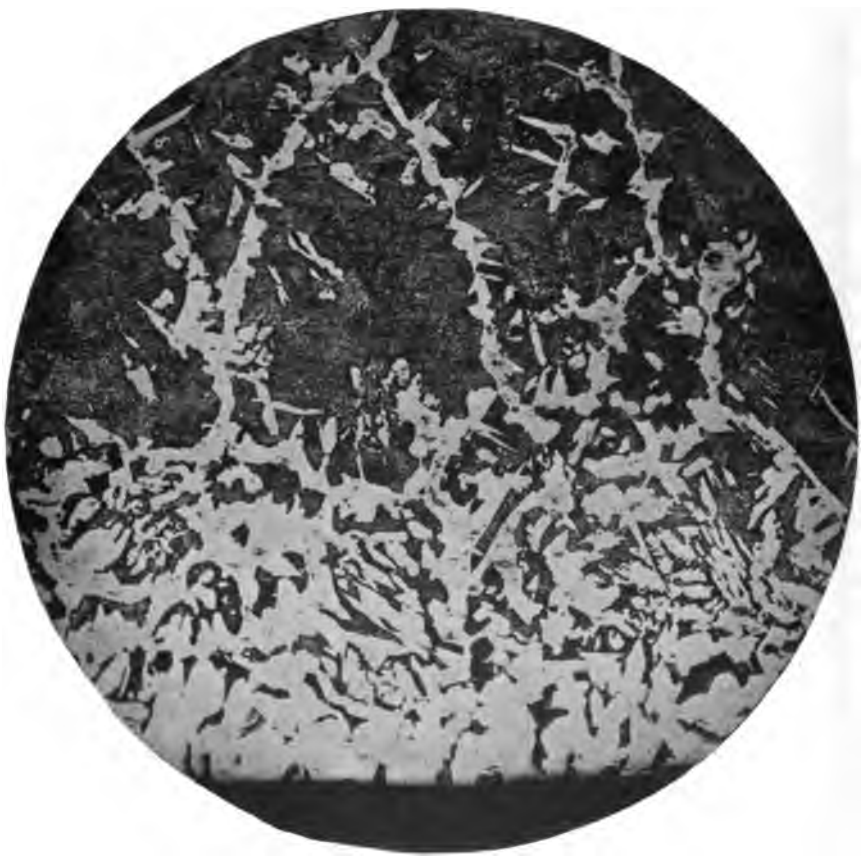
Chemical analysis showed the following to be the composition of this material.

	Per cent.
Copper	89.11
Aluminum	10.00
Iron	.94

Microscopic examination revealed a very fine structure, as shown in micrograph No. 1, magnified 75 diameters. This structure consists of a groundmass or matrix of Alpha solid solution (the lighter constituent) thickly covered with rounded and elongated areas of Beta solid solution (the darker constituent). It will be observed that the Beta constituent is definitely oriented, and that the elongated areas lie in two directions at 60° angles to each other.

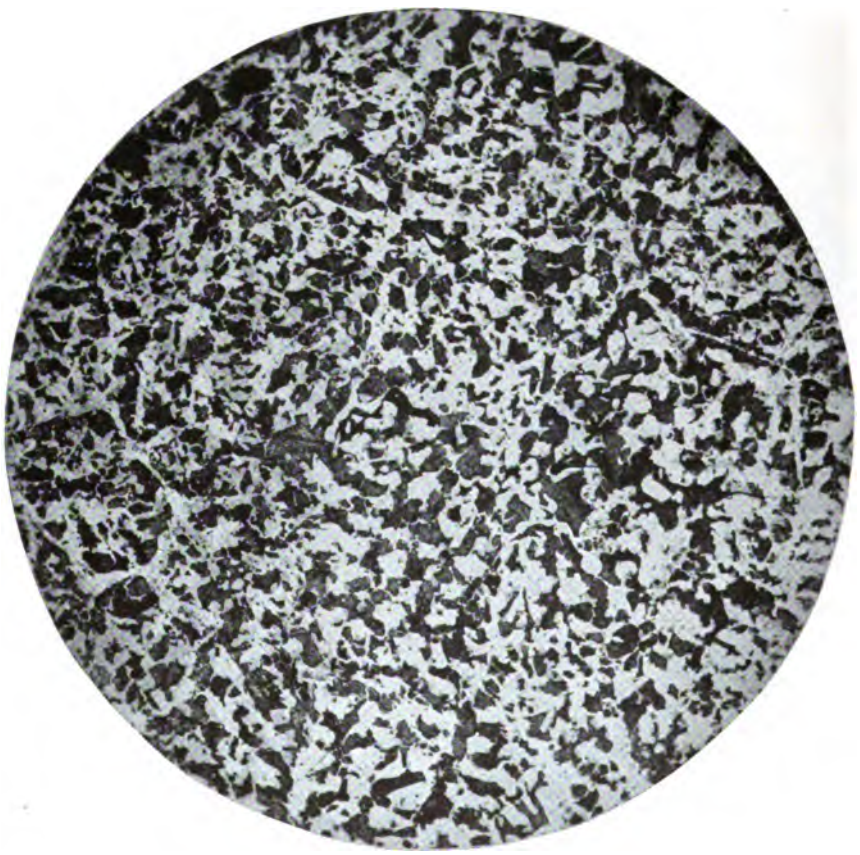
In order to observe what effect quenching would have on the structure of this material, an end from one of the broken test specimens was heated to 900° C. and quenched in water. The structure resulting from this operation is shown in micrograph No. 2, magnified 75 diameters. It is somewhat similar to micrograph No. 1 in that it is similarly oriented, though there seems to be only one unresolvable constituent present, instead of two, as in micrograph No. 1. The structure has an appearance similar to coarse martensite. Brinell hardness after quenching was 166.

PHOTOGRAPH NO. 1. (X4.)



PHOTOGRAPH NO. 2. (×75.)
Showing decarbonized edge.

PHOTOGRAPH NO. 3. (X75.)
Showing general structure as cast.



PHOTOGRAPH NO. 4. (×75.)
Showing refinement of structure by proper heat treatment.

MICROGRAPH NO. 1. (X75.)

MICROGRAPH NO. 2. (X75.)

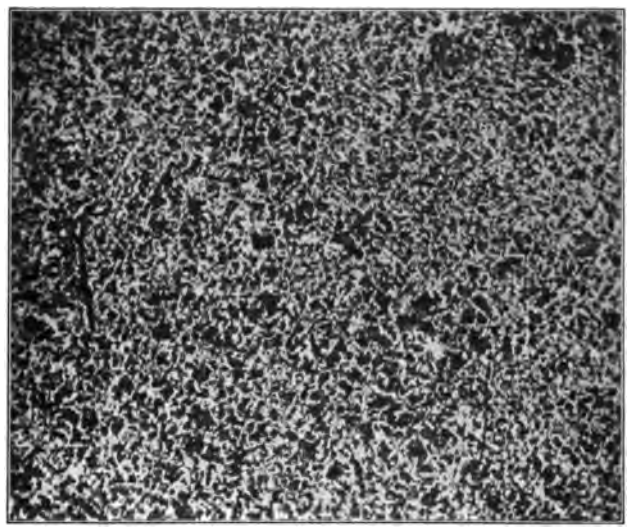
REPORT ON MARKED PRESSURE PLUG SENT TO SANDY HOOK PROVING GROUND.

In connection with the study of erosion of guns, a standard major caliber pressure plug, except that it was free from lettering, was obtained from Frankford Arsenal. This plug was polished and etched on the top of head and examined microscopically. Micrographs No. 1 and No. 2 show the structure at 75 and 400 diameters. This structure was a very fine grained sorbito-pearlite and ferrite.

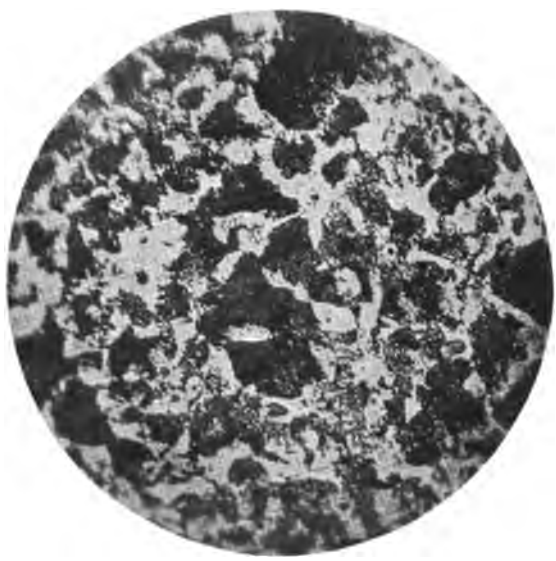
The letters O and V were then stamped on the plug at the pressures indicated on figure 3, and two punch marks were made holding the punch at an angle of 45° with the surface. Photograph No. 3 shows the appearance of the top of the plug when ready to be sent to Sandy Hook.

The plug was returned from Sandy Hook Proving Ground for examination after having been fired 100 rounds. Photographs were made of both letters, some of which are herewith shown.

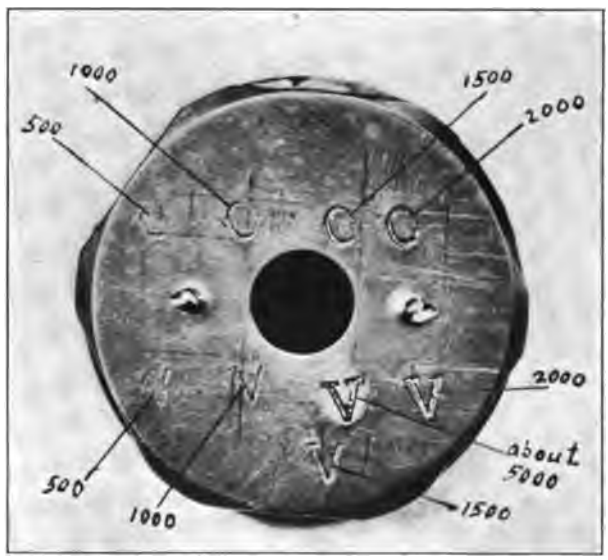
Inspection shows that at those points of maximum pressure there has been the maximum change in the condition of the metal. The metal originally in the sorbitic state has begun to change to the troostitic condition as the result of firing. The relative change is well shown by reference to photographs of the letter V impressed at 5,000, 2,000, 1,500, and 1,000 pounds, respectively. At the lowest pressure there has been little if any change from the original, while in the others the sorbito-troostitic change has been proportional to the pressure. In other words, the effect of cold work upon the sorbite-troostite-martensite change has proceeded through the first change, and the pressure plug has been returned for further firing with the belief that the next change will be accomplished with time as intimated in the Tests of Metals for 1914, "Erosion of guns."



MICROGRAPH NO. 1. (X75.)



MICROGRAPH NO. 2. (X400.)



NO. 3. SLIGHTLY ENLARGED.

PHOTOGRAPH NO. 4. (X50.)
Letter V impressed at 5,000 pounds.

PHOTOGRAPH NO. 5. (X50.)
Letter V impressed at 2,000 pounds.

PHOTOGRAPH NO. 6. (X50.)
Letter V impressed at 1,500 pounds.

PHOTOGRAPH NO. 7. (X50.)
Letter V impressed at 1,000 pounds.

MICROSCOPIC EXAMINATION OF STEEL.

A brochure on the microscopic examination of steel, intended primarily for the use of inspectors of ordnance, has been prepared by the personnel of the laboratory. It has been published in booklet form, as Ordnance Pamphlet No. 1961.

As it is believed that it is of general interest and use, it is reprinted herein.

MICROSCOPIC EXAMINATION OF STEEL.

INTRODUCTION.

This pamphlet is intended primarily for the use of inspectors of ordnance as an aid in the inspection of ordnance material. It is meant to present a mere outline of metallographic methods, and should only be used in conjunction with a study of textbooks on the metallography of iron and steel, and with reference to original papers appearing in the journals bearing on this subject. It should, furthermore, be used with caution, as it is believed the metallographic diagnosis can be made only after much experience in the handling of a variety of materials.

The supreme test of any metal is a test to destruction, but unfortunately this method is usually too expensive and time consuming to lend itself to useful purposes. A practical field test is also satisfactory, but in order to carry on such a test in a systematic manner, a certain amount of information must be obtained previous to the assembling of the materials for such a test. In order to judge whether or not a metal is suitable for the purpose for which it is intended, separate parts of the metal are selected for test and upon the results of these tests the metal is judged as a whole. Physical and chemical tests are usually applied, and both give satisfactory and necessary information within certain limits; but neither is absolutely conclusive in itself, and the results of the two methods of testing should always be used in conjunction.

To further supplement the information obtained by physical and chemical tests, metallographic tests which give information not obtainable by the other methods have been introduced. The particular use of metallographic testing is to give information in regard to the homogeneity of the metal, and the heat treatment to which it has been subjected. These observations are extremely useful in conjunction with the results of the other methods, but are not sufficient in themselves, at the present time, as a basis for conclusion on account of not yet having been sufficiently standardized. Interpretation of results is an important factor, and in cases of doubt the results should be referred to the Watertown Arsenal.

The following pages are submitted as a help to inspectors, who should inform themselves more fully in regard to underlying principles involved and to methods employed.

SLOWLY COOLED STEELS.

When steel passes from the liquid to the solid state it forms what is called a solid solution. The temperature at which the change from liquid to solid metal takes place is progressively lowered with increase

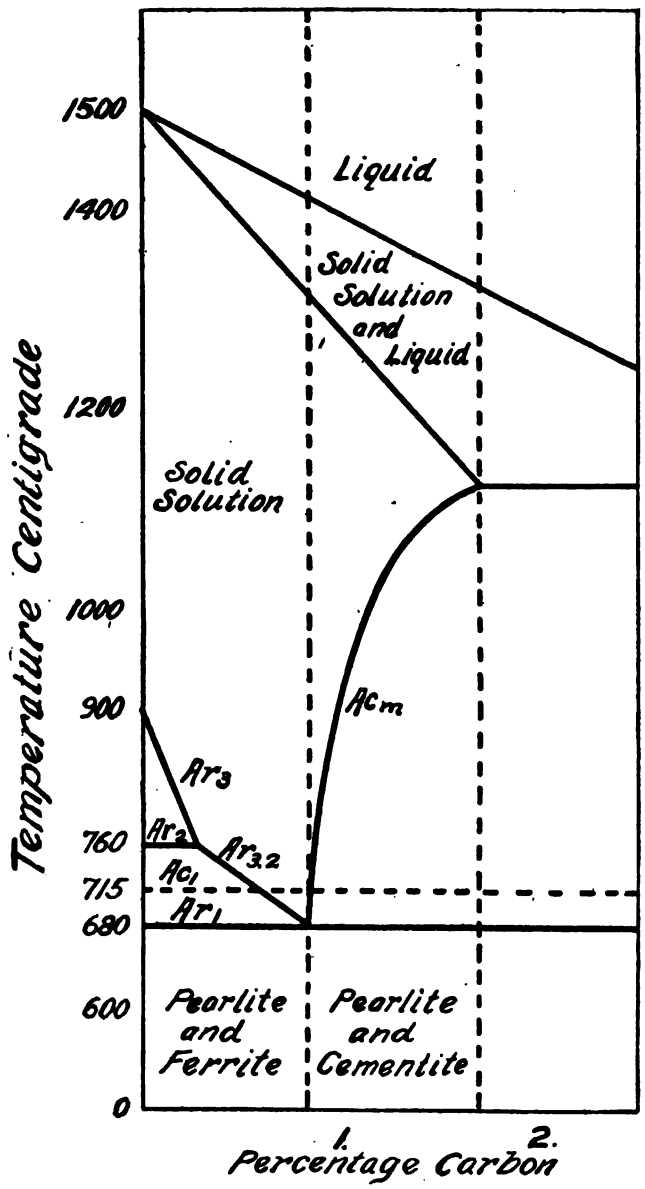
of carbon. The resulting solid solution is subject to certain reactions which take place as the solid mass is further cooled. The temperatures at which these reactions take place are known as "critical temperatures," or critical points, and are made evident by evolutions or absorptions of heat. The reactions are reversible ones, depending upon whether the points are observed on a rising or falling temperature. Points obtained upon a falling temperature are referred to as Ar_3, Ar_2, Ar_1; points obtained on a rising temperature as Ac_1, Ac_2, and Ac_3.

The reactions which take place at these critical temperatures determine the character of the resulting product. Inasmuch as some of these points are dependent upon the percentage composition of the metal, particularly carbon, the properties of any steel are then dependent upon the percentage of carbon and the completeness with which the reactions have taken place at the critical temperatures.

For practical purposes the Ar_2 and Ac_2 points need not be considered. In steels containing less than 0.85 per cent C. the Ar_3 point represents the beginning of the decomposition of solid solution and the throwing out of some of the solvent, viz, iron. The temperature at which this reaction begins is progressively lowered with increase of carbon up to 0.85 per cent. In steels containing more than 0.85 per cent C. the upper critical temperature is progressively raised with increase of carbon up to 1.7 per cent C. and is referred to as Acm. and the reaction taking place represents the beginning of the separation of iron carbide, Fe_3C, on a falling temperature, and the completion of solution of iron carbide on a rising temperature. The Ar_1 point for all carbon steels is approximately at the same temperature and represents the final decomposition of the solid solution into its constituents, iron and iron carbide. The Ac_1 point is approximately 30° higher than the Ar_1 point and represents the beginning of the formation of solid solution. In steels containing 0.85 per cent C. there is but one critical temperature at which the solid solution decomposes into its constituents, iron and iron carbide. This is known as an eutectoid steel, and its microscopic constituent is pearlite. Pearlite always etches dark, and under high magnifications is shown to consist of alternate laminations of iron and iron carbide. Steels containing less than 0.85 per cent C. are hypoeutectoid and contain the microscopic constituents of ferrite and pearlite, the amount of the latter increasing with the per cent of carbon. Steels containing more than 0.85 per cent C. are hypereutectoid and contain the microscopic constituents cementite (iron carbide, Fe_3C) and pearlite. These facts are illustrated in the diagram. (Fig. 1.)

Hypo-eutectoid steels are used for forgings and castings; hypereutectoid steels for tools; eutectoid steels for tires, springs, etc. Examples illustrating these constituents are shown in photographs Nos. 1–9.

Photograph No. 1 shows the characteristics of a carbonless iron in which the whole field is made up of granules of ferrite. With the introduction of carbon there is a decrese in the amount of ferrite and the constituent pearlite begins to appear. This is shown in photograph No. 2, for a steel containing 0.18 per cent C. Inasmuch as steels containing 0.85 per cent C. contain 100 per cent pearlite, and pearlite being composed of ferrite and cementite, in this steel containing 0.18 per cent carbon there ought to be approximately 20



Portion of iron-carbon diagram

Fig. 1

per cent of the field made up of pearlite. In a steel containing 0.5 per cent C. there should be 58.8 per cent pearlite. Such a steel is shown in photograph No. 4. A eutectoid steel containing 0.83 per cent C. and practically 100 per cent pearlite is shown in photograph No. 7. Under higher magnifications pearlite shows the laminated structure shown in photograph No. 8. In hypereutectoid steels the excess carbon beyond that necessary to form pearlite separates as free cementite and the amount of free cementite can be calculated. Inasmuch as the whole field is made up of pearlite and cementite and it requires 0.85 per cent of the carbon to form the pearlite, the difference between the total carbon and 0.85 per cent C. gives the amount of carbon available to form cementite. Thus, in a steel containing 1.25 per cent C. there is available for cementite formation 0.4 per cent C. And as cementite, Fe_3C, contains 6.67 per cent C. the 0.4 per cent carbon would furnish approximately 6 per cent cementite which would occur in the free state, and the steel would contain 94 per cent of pearlite and 6 per cent cementite. (See photograph No. 9.) It is thus evident that by microscopic examination a rough determination of carbon may be made on slowly cooled steels. Photograph No. 10 shows a steel containing 1.46 per cent carbon—approximately 9 per cent cementite—in which the white constituent is cementite.

RAPIDLY COOLED STEELS.

Every chemical reaction has a time factor. In the slow cooling or heating of steels the reactions taking place at the critical temperatures are almost complete and the products of the reactions are in a state of stable equilibrium. If this time factor be disturbed the state of equilibrium is also disturbed. If the rate of cooling is rapid enough the reactions which ordinarily take place on slow cooling are suppressed and the metal is maintained in the condition in which it existed at the temperatures from which cooling began. If cooled rapidly from above Ar_1, the reactions which ordinarily take place on slow cooling have not time to take place, and the solid solution present persists at the ordinary temperatures, but, inasmuch as solid solution of iron carbide in iron is in stable equilibrium only at temperatures above Ac_1, then it must be in a state of unstable equilibrium at the ordinary temperature. This is the condition of hardened steel and is produced by quenching in water, brine, or oil at some temperature above Ac_1. The tendency toward stable equilibrium is very small at the ordinary temperature, but it increases with rise of temperature and time. The microscopic constituent produced in quenched steel is known as martensite and is characterized by needle-like crystals crossing each other at angles of 60°. Photograph No. 11 shows the characteristic appearance. Commercially, martensitic steels are unimportant on account of their extreme brittleness, and they are found only rarely.

More important, however, are those steels in which the unstable state of equilibrium has been partially relieved by the process known as tempering or drawing.

If heated to temperatures below Ac_1 the effect produced will vary with the temperature. The lower the temperature of reheating the

smaller is the tendency toward stable equilibrium; the higher the temperature the more stable is the product produced. Practically any degree of hardness may be produced, varying from glass to extreme softness, by properly regulating the temperature of the heating. There are then two extremes, the martensitic steels formed by quenching from above Ac_1 and the pearlitic steels formed by cooling slowly from Ar_1 or above. Intermediate between these extremes are steels in which more or less of the unstable solid solution has been partly converted to more stable forms. Such forms are represented microscopically by troostite and sorbite. Troostite, formed by tempering at relatively low temperatures, represents the first stage in the breaking down of the unstable equilibrium and is characterized by the amorphous or slighlty granular structure. On etching with alcoholic nitric acid the surface usually blackens immediately from separated carbon. Photograph No. 12 shows troostite.

Sorbitic steels are those which have been quenched and heated to a higher temperature and thus represent a more stable state of equilibrium. They are characterized by having a peculiar grayish color, and the structure is better defined than troostite. The particles of iron carbide have not assumed definite laminations with ferrite as in pearlite, but are very much more distinct than in troostite. Photograph No. 13 shows sorbite.

Similar effects may be produced by varying the rate of cooling. Thus, if the steel be quenched in the critical range at the beginning of the transformation of solid solution into its components, troostite may be produced; if quenched near the end of the transformation, sorbite may be produced. Quenching below the critical range should theoretically produce the same effects as slow cooling.

ANNEALED STEELS.

In the heating of steels to a high temperature, and in the slow cooling from a high temperature, either without having been forged or after having been forged at a high temperature, there is considerable grain growth of the steel with strong tendency toward granulation. In the making of castings there is good opportunity for grain growth and also for the formation of internal strains. To remove strains and to refine the grain, steel is annealed. The temperature of annealing is determined by the percentage of carbon. For hypoeutectoid steels the temperature most suitable is coincident with the temperature at which complete diffusion or solution of the constituents takes place. This corresponds to the Ac_3 point, and for steels containing less than 0.85 per cent C. is progressively lowered from 900° C. for pure iron to 700° C. for eutectoid steel. Usually a temperature 25–50° higher should be reached.

In hypereutectoid steels the tendency for the structure to coarsen is very much greater, and consequently the heating for annealing should be carried only a little over the Ac_1 point.

Microscopic examination gives a clue not only to the temperature at which a steel has been annealed, but also gives a very strong indication of the rate at which cooling has taken place.

NONMETALLIC IMPURITIES.

In addition to the normal constituents of steel, there are some abnormal constituents commonly classified under the name of slag, which may include such substances as silicate of manganese, sulphide of manganese, and oxide of iron. Mixtures of silicates of iron and manganese may occur and also mixtures of silicates of manganese and sulphide of manganese. Oxide of iron ordinarily occurs near the surface as the result of rolling in the same mill scale, but may at times penetrate quite deeply into the interior, and in either case is usually accompanied by partial decarbonization.

It is difficult at times to distinguish readily between silicate and sulphide of manganese without resort to special tests. They both occur as dove-colored constituents and are best observed on the polished but unetched surface. (See photos. Nos. 17 and 18.) The former, especially if occurring in masses, will frequently show crystalline-etch figures. (See photos. Nos. 14 and 15.) In slowly cooled, unworked steels they will show as rounded dove-colored masses usually in the ferrite; in forged steels they are elongated in the direction of forging. (See photos. Nos. 16 and 17.) Inasmuch as all steels contain some slag, it is a matter of opinion as to how much should be allowed. The form in which it occurs is of greater importance than the actual amount present, although the smaller the amount of slag the better the product. It is especially undesirable to have the slag in masses, and particularly in elongated streaks. It then produces ghost lines and is usually accompanied by streaks of ferrite which are usually further embrittled by the presence of high phosphorus. Such slag streaks are frequently the source of cracks which develop along the slag in the direction of forging.

By reference to photographs Nos. 14 to 18 may be seen some of the forms in which slag may occur, and other examples may be seen under the discussion of special cases.

Inspectors should observe the following:

1. Macrostructure for (*a*) ingot structure, (*b*) segregation, and (*c*) blowholes.
2. Slag.
3. Streaks.
4. Heat treatment.
5. Composition.

Macrostructure is the appearance of the etched surface seen by the naked eye. Microstructure, on the other hand, is that appearance of the etched surface seen under a microscope. The macrostructure often yields important evidence concerning the qualities of the metal. The structure is usually developed on a roughly polished area of considerable size, or if it is possible to work only with small sections, it is recommended that the test bars be rough polished on two sides, at right angles to each other, before being turned into shape. The development of the structure is accomplished by etching the surface with a 6 per cent solution of iodine in alcohol or with an 8 per cent solution of copper ammonium chloride. The former should always be prepared immediately before use, as it keeps in good condition only a relatively short time. The copper ammonium chloride should be used only for those specimens which can be dipped

into it, and the time of action should be approximately one minute. This solution will not give results with alloy steels on account of the tenacity with which the deposited copper adheres to the surface. With carbon steels the deposited copper is very easily removed by rubbing with a piece of wet cotton.

In using the iodine the polished surface is swabbed with cotton holding the reagent, and the process is repeated as fast as the color of the iodine disappears for a period of five minutes. The macrostructure thus developed shows: Ingot structure, segregation of carbon or phosphorus, excessive slag, strained metal.

The presence of ingot structure such as shown in photograph No. 19 indicates that the heat treatment and forging have not been sufficient to wipe out the crystallization which occurred on the solidification of the metal. It is not definitely known that the presence of ingot structure is harmful, and it is frequently accompanied by excellent microstructure, but it serves as an indication of the heat treatment to which the metal has been subjected after solidification. It is believed that such a structure would not be found in the best steel, and it is further believed that metal showing ingot structure would be more liable to rupture from shock than metal in which the ingot structure had been wiped out by heat treatment and forging.

Segregation of carbon or phosphorus may be brought out most successfully by etching a complete cross section of the metal under investigation, such as shown in photograph No. 20 of a rail section in which segregation of carbon is shown, or in photograph No. 21 of a cross section of a piece of cold-rolled shafting in which segregation of phosphorus is shown. Photograph No. 22 shows a longitudinal section of the same piece of shafting, and is etched with nitric acid, which darkens the phosphide areas. It is seldom possible, however, to obtain complete cross sections, but valuable indications may be obtained from surface structures or from test-bar sections such as shown in photograph No. 38 of test bars marked 2, 3, and 5. The phenomena observed here will be more fully discussed later.

Both iodine and copper ammonium chloride show dark areas where segregated carbon occurs; iodine leaves phosphide areas whiter than the surrounding metal, while copper ammonium chloride leaves the area dark and the copper adheres more tenaciously to a phosphide than to a carbide area. Excessive slag is shown by a pitted or spongy area where the slag has segregated.

Strained metal invariably etches more darkly than metal which has not been strained, and the extent of the strained area may be determined by etching with either reagent. Photograph No. 23 shows an area which has been strained by cold work.

Slag.—Slag is undoubtedly harmful if the material, either silicate or sulphide, occurs in large quantities in segregated masses, or if present in masses elongated in the direction of forging. The position of the slag in the metal is also of importance, and that which occurs in regions of severest strain is most to be feared. It must always be remembered that in observing slag the particular spot in view is magnified 50 to 100 diameters and it may be only an isolated spot. If found, an exploration in the neighboring region should be made to see if it is generally distributed. It should also be remembered that low-carbon steels may carry with safety more slag than high-carbon

steels. In photographs Nos. 14, 15, 16, 17, 53, 54, and 55 are shown slag areas which would at once arouse suspicion, and if found in ruptured material an exploration would more likely show similar areas throughout the region of fracture.

The inclusion of oxide is frequently accompanied by partial decarbonization and is most frequently found on or near the surface. An example of this is shown in photograph No. 24, in which it is seen that a crack has penetrated through the slag, probably mill scale, and in the crack are the remnants of the slag. On the left of the crack is the normal structure and on the right is a decarbonized area containing slag. Such an area would probably be large enough to show to the naked eye and would be considered unsafe. Other examples of oxide inclosures are cited on pages 259 and 260 in the discussion of the failure of 12-inch gun and 14-inch gun lever.

Streaks.—On machining a metal there may often be seen lines or areas on the surface which have a different luster from the main mass of metal and which frequently machine quite differently from the metal surrounding it; or on polishing and etching, lines of different luster may stand out prominently and invariably elongated in the direction of forging. Such lines or areas are known as streaks or ghost lines and may occur as either dark or light in comparison to the surrounding metal. Streaks are usually accompanied by slag. If the slag is oxidizing in character, the streak will be decarbonized, and at the same time the ferrite areas will be embrittled by being rich in phosphorus. Such streaks may be the source of fracture and should be looked upon with suspicion.

Dark-colored streaks usually contain silicate of manganese and are less harmful, the metal showing considerable ductility in the streaked region.

Radial test pieces from gun forgings will frequently show streaks, and on account of the tension being normal to the direction of extension, the specimen will show low ductility. Photographs Nos. 25 and 26 show, respectively, dark and light streaks, and photograph No. 27 shows the microstructure of a portion of the light-colored streak with its decarbonization and accompanying slag. (See also "Tests of Metals" for 1909, vol. 2.)

Heat treatment.—It is important that the heat treatment should represent the best practice. This will vary with the purposes for which the material is to be used. In annealed steels the structure should not only show the finest grain which it is possible to give the material, but it should be uniform throughout the metal, considering, however, that the mass of metal influences the structure. Thus the surface indications are not always the same as would be found in the center of a large section. Variations between the exterior and interior should therefore be expected on account of slower cooling of the interior and the inability to always have the forging affect the whole mass of metal alike. Coarse structure on the surface will usually indicate coarser material in the center of the mass. Coarse structured material may pass physical specifications, but, nevertheless, it does not represent the best practice. Photographs Nos. 28 and 29 represent respectively coarse structure and fine structure of the same material, and the latter is undoubtedly the better material, as may be seen from the respective physical properties. Photograph No. 30 shows an undesirably coarse structure, and No. 31 shows a

crystalline structure which is not only undesirable but which could have been avoided by suitable heat treatment.

Failure to obtain uniformity of structure is shown in photograph No. 32. Discussion of photographs Nos. 49, 51, and 53 will be found under the discussion of some of the special cases, viz, the failure of 14-inch gun lever arm. Dangerous overheating is shown in photograph No. 33. In this case the material is burnt, as is shown by the oxide between the granules of pearlite.

In material which has been quenched and subsequently tempered, there is greater difficulty in defining the structure, but in general it should be fine and usually sorbitic, unless in unusual cases, especially high strength and lower ductility is desired, in which cases troostite may be found. In steels in which it is desired to have high strength and high ductility and obtained by either oil or water quenching, followed by a tempering process, and in which the structure is usually sorbitic, it should be observed that the original martensitic structure be completely removed by the tempering process. This point is illustrated by photograph No. 34 in which there are distinct remains of the original martensitic structure. Such a steel properly heat treated ought to show a structure similar to Nos. 12 or 13.

Composition.—On slowly cooled or annealed steels, the percentage of carbon may be roughly estimated. On quenched steels this estimation is much more difficult and usually impossible. However, with some experience, the observer can tell approximately whether or not the percentage of carbon is what the specifications call for. The chemical analysis, however, gives more accurate data and should always be relied upon for final decision. In certain cases, however, a rough microscopic analysis may be made with advantage. For example, in photograph No. 35 (broken recoil spring), there is plainly an excess of cementite, indicating, as was subsequently shown by analysis, about 1.25 per cent of carbon. Such material is evidently unsuited for spring steel on account of the presence of the weak and very brittle constituent, cementite. The main body of this spring showed troostite, not in itself unsuitable, most of the carbon being in solid solution, but the center portion was not cooled rapidly enough to prevent the separation of free cementite. The conclusion is evident that a steel containing less carbon would have been more suitable.

THE EFFECT OF WORK ON GRAIN SIZE.

Steel cooled slowly and undisturbed from a high temperature will show a coarsely granular or crystalline structure, and the size of the grain is a function of the temperature and the time during which the material was held at the maximum temperature, and the rate at which the material was cooled. In large masses of material the structure will be coarser in the center than at the surface, due to the difference in rate of cooling. In order to overcome this difference and at the same time to produce a homogeneous, uniform material the steel is worked during the period at which grain growth would ordinarily take place. Steel which has been hot worked down to the Ar_1 point will show a finer grain, and will be stronger than the same steel slowly cooled without work, and will at the same time show high ductility. Examples of steel worked and unworked are shown

in photographs Nos. 29 and 28. Steel which has been worked below Ar_1—cold worked—will show considerable distortion of grain, as shown in photograph No. 36.

The following illustrations will serve to indicate types of structure which have been found in defective material which failed in service.

10-INCH RIFLE, MODEL 1895.

The tube of this gun was found to be cracked after proof firing. The crack was situated about 2 feet in from the breech end and extended in the form of a crescent through a visible distance of about 10 inches. At the central portion of the crack the walls were considerably more separated than at either end, and considerable metal had been removed at this point. The general appearance is shown in photograph No. 37. It will be noted that the crack is not continuous.

Photographs No. 38 and No. 39 show the macrostructure of this steel when etched with iodine, the specimens shown in photograph No. 38 being taken longitudinal, radial, and tangential. The segregation of phosphorus is indicated by the dark lines in pieces No. 2 and No. 5 of photograph No. 38, and in both pieces of photograph No. 39, and by the dark spots in piece No. 3. Photograph No. 39 shows the metal cut from the region of the fracture and treated in the same manner, as shown in test piece marked 5 in photograph No. 38, and in other test pieces not shown. The dark streaks were found to be elongated parallel to the direction of forging, and it is reasonable to suppose that the elongation will always be parallel to the surfaces being forged. By inspection of the two larger pieces of metal cut from the region of the crack, photograph No. 39, it will be seen that there is considerable distortion of the phosphide areas near the rifled surface. This would seem to indicate that by some means a fold in the metal had taken place at this point and that in forging it out the phosphide areas had been distorted to the same extent as the surface of the fold.

In photographs of test piece No. 3 is shown a face cut normal to the direction of forging. In all specimens cut in a similar direction there is always the same evidence of ingot structure or primary crystallization, which is indicated by the appearance of the white interpenetrating lines as shown. This crystallization was produced at the time of the passage of the metal from the liquid to the solid state, and during the cooling from the temperature of solidification to about 700° C. This is characteristic of ingot crystallization.

Subsequent heat treatment and forging should have completely eliminated all traces of this, and its presence is an indication of faulty manipulation. Further evidence of faulty heat treatment is found in the microstructure of the steel.

Examination of sections in the vicinity of the crack showed many fine cracks, slag inclusions, and carbonless areas. The cracks led to slag, and where the slag was found there was also found decarbonized areas. Photograph No. 40 shows a crack ending in slag and surrounded by decarbonized iron. The course of the slag was quite irregular, as shown in photographs No. 41 and No. 42.

That the slag originated during the process of forging and was folded into the metal rather than during the manufacture of the steel

is indicated by the fact that it is strongly oxidizing in character. If it had originated at the time of making the steel, and had then burned out some of the carbon, there would still have been plenty of time for more carbon to have diffused back into these areas. It is found here, however, surrounded by free ferrite along the slag lines, as shown in photograph No. 43 and in photograph No. 44, in which is shown an isolated slag spot surrounded by free ferrite, and this in turn by the normal structure.

Examination was made of the surfaces normal to the lands and grooves of the rifling, and there was no evidence of hardening of the surface. It is thus highly improbable that a crack could have originated from the presence of hardened metal.

It is believed that the crack in this gun was caused by folding in of some of the metal during forging. Incidently some other defects are pointed out.

14-INCH GUN LEVER.

This lever was made of cast steel and was broken during the test of the carriage. A microscopic examination revealed the structures shown in photographs Nos. 46–51, inclusive.

Photograph No. 46 shows a large amount of segregated ferrite with included slag. These ferrite areas are of such a size that they are easily visible to the eye.

In the fractured ends of the test pieces the metal shows decidedly bright spots, and these are due, it is believed, to the presence of the segregated ferrite. Further, it has been noticed that along the stem of the test pieces there are incipient cracks developed, as shown in photograph No. 45. It is highly probable that these incipient fractures are developed in such areas as shown in photograph No. 47, which shows a large ferrite field at the edge of the specimen. It is possible that if the forces are transmitted equally throughout the test piece that such a portion would yield more readily where the carbon was lowest. The strength of such a spot would be approximately that of pure iron, or about 40,000 pounds per square inch, while the darker areas which contain more carbon would show considerably higher values. The presence of much slag in the ferrite areas would also increase the brittleness at this point, and would account for the low ductility in some specimens. Further examples of this form of segregation are shown in photographs No. 48 and No. 49.

The metal has not been annealed in such a way as to remove the original crystallization which took place at the time of solidification. The crystalline structure is shown in photographs Nos. 50 and 51. Proper annealing should have completely wiped out all appearance of this kind. Evidence of this crystalline nature was found in all specimens examined, and it is highly probable that wherever such structure appears, casting strains exist. Proper annealing would also have removed all initial strains and would have refined the structure.

The strength and ductility have undoubtedly been affected by the aforementioned factors, viz, segregated ferrite, crystalline structure, and abundance of slag.

12-INCH NAVY GUN.

A section of the metal, 1 inch square, was cut from the region of the fracture, and the macrostructure was developed by etching with iodine solution. Photograph No. 52 shows the macrostructure in which is shown several streaks running parallel to the direction of forging on the left hand face, and on the right hand face an irregular area of segregation normal to this surface. Small fissures were visible and both faces indicated the presence of slag. Photograph No. 53 shows the microstructure on the longitudinal face in which is seen slag and small fissures. Photographs Nos. 54 and 55 show an unetched and etched area in the longitudinal face, some of the same slag areas being shown in each, and the lack of homogeneity of the metal is evident.

The cause of rupture is believed to have been due to the presence of a zone of streaked metal, and further, that this resulted from the presence of slag in the original ingot.

POLISHING.

To prepare a specimen for microscopic examination, it is necessary to polish the surface until a perfectly smooth finish is obtained. Frequent examination under the microscope will enable the operator to determine when the polishing should end. Small specimens are easiest to handle, and the threaded ends of broken test specimens are commonly used. The broken ends are cut off with a saw and smoothed with a dead smooth file, then rubbed on a piece of No. 120 emery cloth and later on a piece of No. 00, care being taken to change direction frequently so that the scratches are at right angles to each other. The piece is then rubbed on a block of wood covered with felt or canvas and moistened with a preparation of flour emery and water. This is usually applied with a fine 2-inch brush.

The specimen is then rubbed successively on similar blocks moistened with tripoli and jeweler's rouge. The piece should be carefully cleaned before changing from one abrasive to another.

If power is available, it will be found much easier to polish the specimens on rapidly revolving wheels covered with fine duck or broadcloth, to which the abrasive is applied with a brush or in the form of a spray.

After polishing, the specimen is washed carefully in running water and immediately wiped dry with a towel or piece of absorbent cotton.

It is recommended that Appendix 1 of Sauveur's "Metallography" be carefully read.

ETCHING.

An alcoholic solution of nitric acid is the most common reagent used for etching, and is prepared by adding 4 c. c. of nitric acid to 96 c. c. of grain alcohol.

A small quantity of the acid solution is placed in a porcelain dish, and the polished surface of the prepared specimen immersed for about 10 seconds, the specimen being agitated to prevent adhesion of gas to the surface. It is then removed and washed thoroughly in running water or in alcohol and quickly dried either by a soft cloth or by a blast of air. Examination under the microscope will deter-

mine whether the etching has been carried far enough. The time of etching will vary, depending on the hardness of the steel, and therefore the period must be learned by experience.

A 5 per cent alcoholic solution of picric acid is sometimes used for a reagent, and on low carbon soft steels it gives practically the same indications as the alcoholic nitric acid. Its use on hardened or tempered steels is not recommended.

Sodium picrate is used to distinguish between ferrite and cementite. This solution is made by dissolving 2 grams of picric acid in 98 c. c. of a solution of 250 grams of caustic soda (NaOH) dissolved in 750 c. c. of water. The polished specimen is immersed in the boiling solution for 5 to 10 minutes, when the cementite, if present, assumes a blackish coloration. Ferrite remains bright when boiled in sodium picrate solution.

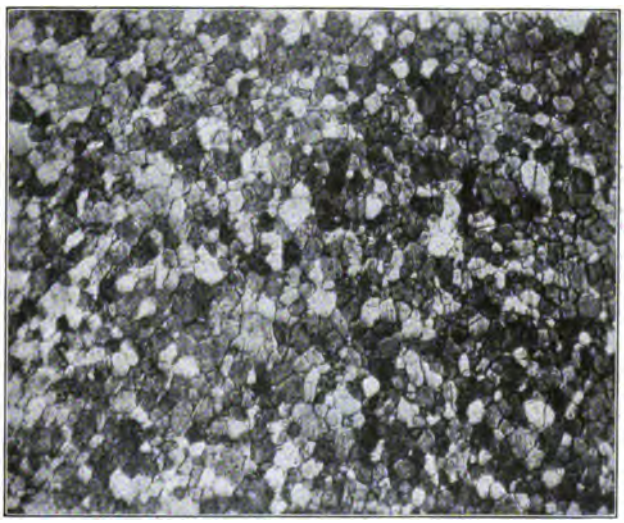
If a permanent record is desired, photo-micrographs are made; the magnification being always marked on the print. It will be found that polished surfaces will oxidize if exposed to the air or to moisture. Specimens should be washed in alcohol and stored in air-tight boxes.

For the examination of large pieces of metal, such as guns, etc., it will be sufficient to polish spots about the size of a 50-cent piece. This can be done with any of the portable outfits now on the market or may be done by hand.

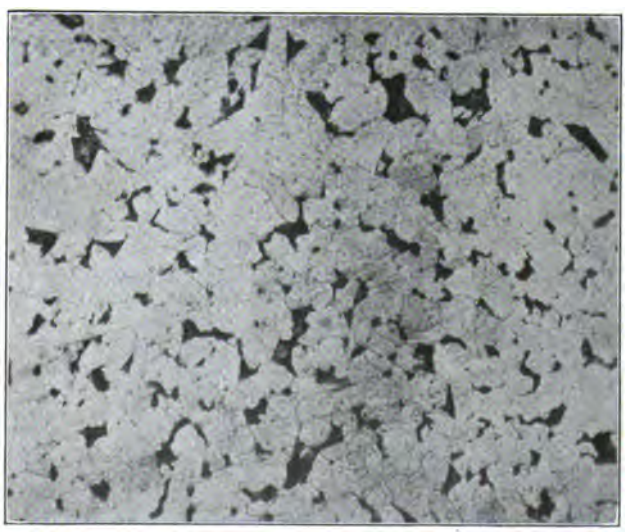
The study of the following books is recommended to supplement the information contained herein: Sauveur's "Metallography of Iron & Steel"; Desch, "Metallography"; Osmond & Stead, "Microscopic Analysis of Metals"; Howe, "Iron, Steel, and Other Alloys."

In conclusion it may be stated that there is a tendency to overrate the application of metallography. Used in connection with the physical tests and chemical analyses it furnishes valuable supplementary data. The inspector is warned to be conservative in his conclusions, at least until he has acquired sufficient experience in the examination of steels to make his conclusions agree with the facts.

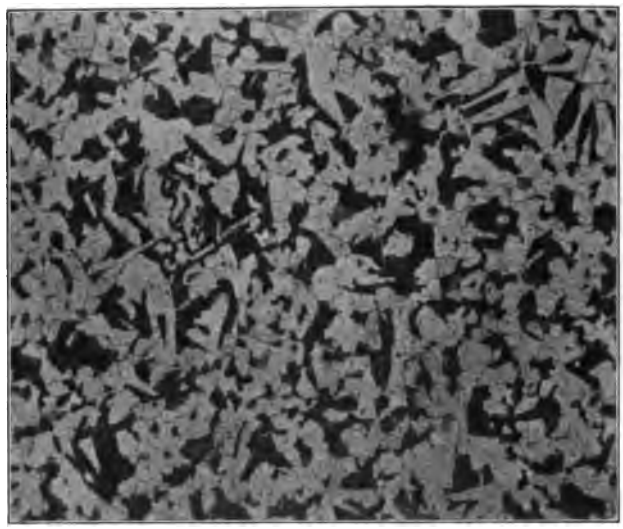
It will be found that by the examination of specimens whose heat treatment is definitely known, the inspector will soon acquire a fund of valuable information which will enable him to diagnose an unknown steel correctly. Defective metal should be examined and its characteristics noted whenever and wherever it is found.



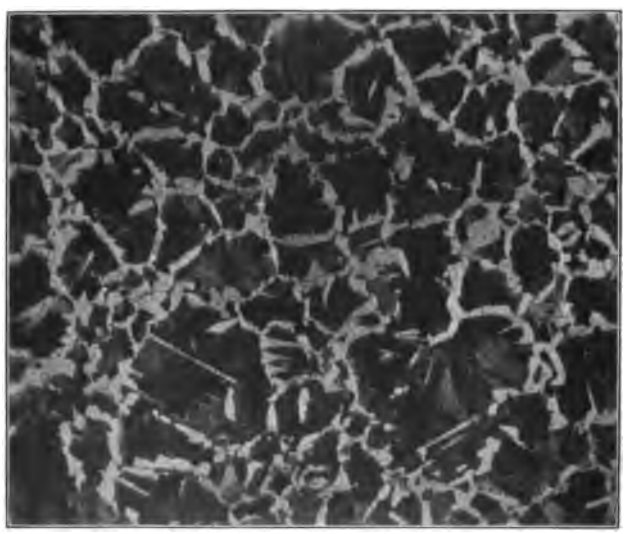
PHOTOGRAPH NO. 1. (X75.)
0.06 per cent carbon. Approximately pure ferrite.



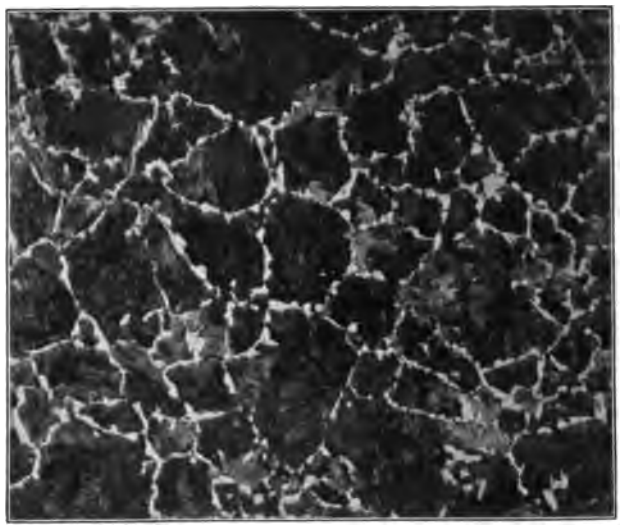
PHOTOGRAPH NO. 2. (X75.)
0.18 per cent carbon. Ferrite (white) and pearlite (dark).



PHOTOGRAPH NO. 3. (×75.)
0.32 per cent carbon. Ferrite (white) and pearlite (dark).



PHOTOGRAPH NO. 4. (×75.)
0.49 per cent carbon. Ferrite (white) and pearlite (dark).



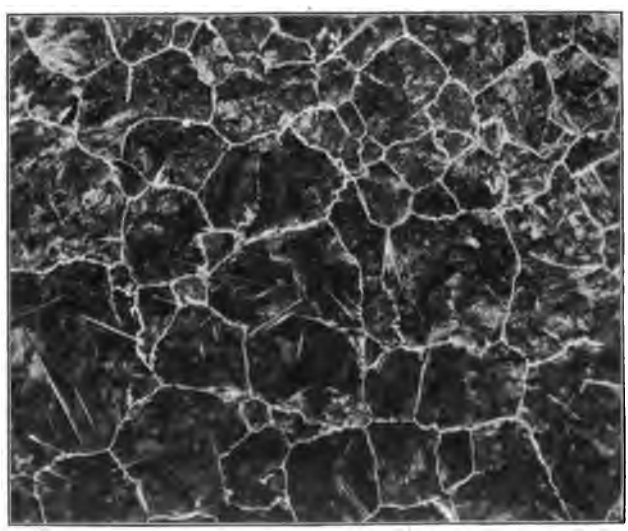
PHOTOGRAPH NO. 5. (X75.)
0.57 per cent carbon. Ferrite and pearlite.

PHOTOGRAGH NO. 6. (X75.)
0.71 per cent carbon. Ferrite and pearlite.

PHOTOGRAPH NO. 7. (×75.)
0.83 per cent carbon. Pearlite.

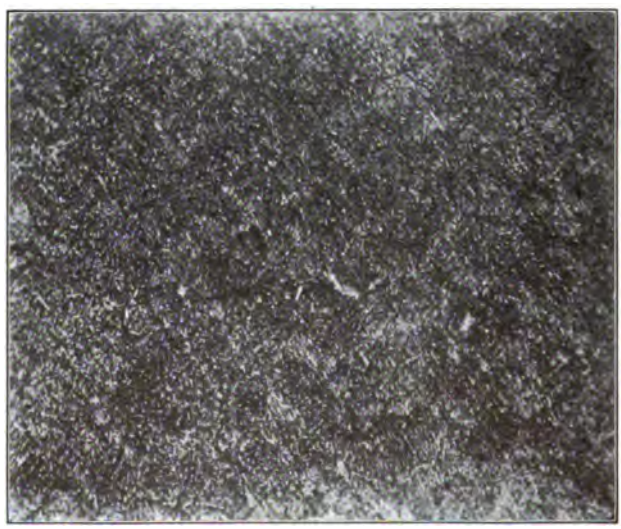
PHOTOGRAPH NO. 8. (×485.)
0.83 per cent carbon. Pearlite.

PHOTOGRAPH NO. 9. (×75.)
1.22 per cent carbon. Pearlite and cementite (white).

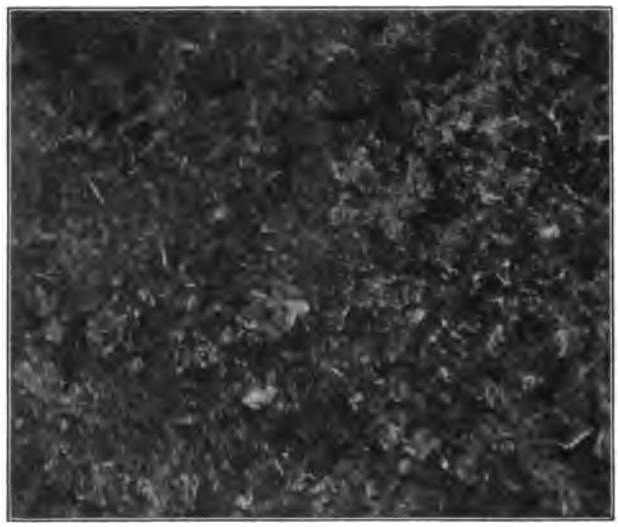


PHOTOGRAPH NO. 10. (×75.)
1.46 per cent carbon. Pearlite and cementite (white).

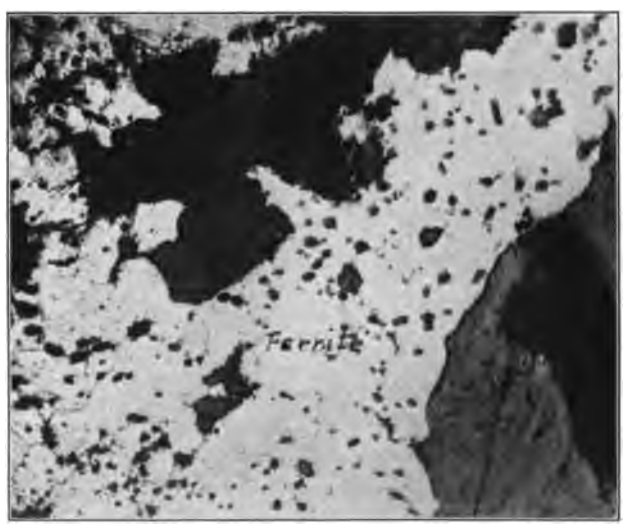
PHOTOGRAPH NO. 11. (X75.)
Martensite.



PHOTOGRAPH NO. 12. (X75.)
Troostite.



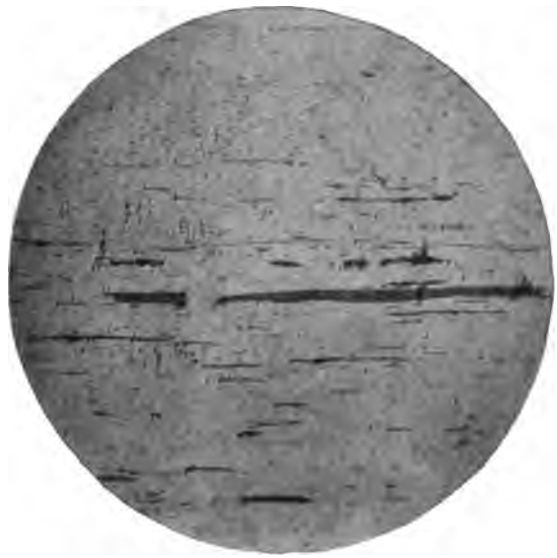
PHOTOGRAPH NO. 13. (X75.)
Sorbite.



PHOTOGRAPH NO. 14. (X50.)
Ferrite and massive silicate of maganese. Etch figures in the silicate.
(Ferrite, white; silicate, dark.)

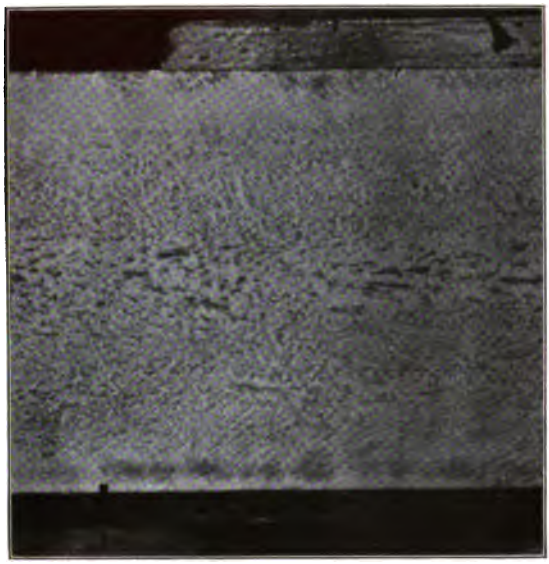
PHOTOGRAPH NO. 15. (×50.)
Etch figures in silicate of maganese, and cavities due to removal of silicate.

PHOTOGRAPH NO. 16. (×50.)
Sulphide of manganese in gun steel.



PHOTOGRAPH NO. 17. (X5C.)
Slag elongated in direction of forging. Specimen unetched.

PHOTOGRAPH NO. 18. (X50.)
Unevenly distributed slag. Specimen unetched.

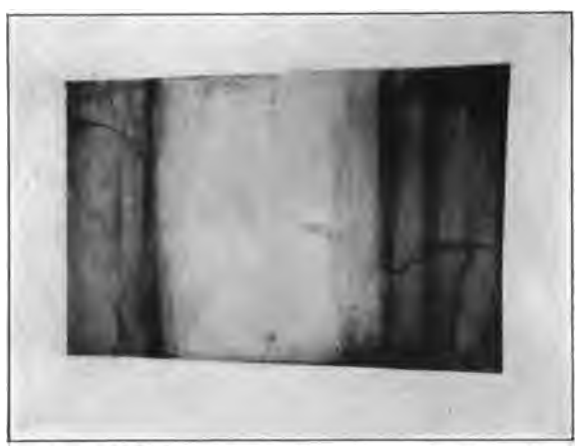


PHOTOGRAPH NO. 19. (ONE-THIRD SIZE.)
Ingot structure in steel

PHOTOGRAPH NO. 20.
Cross section of steel rail showing segregation in center of head, web, and base.

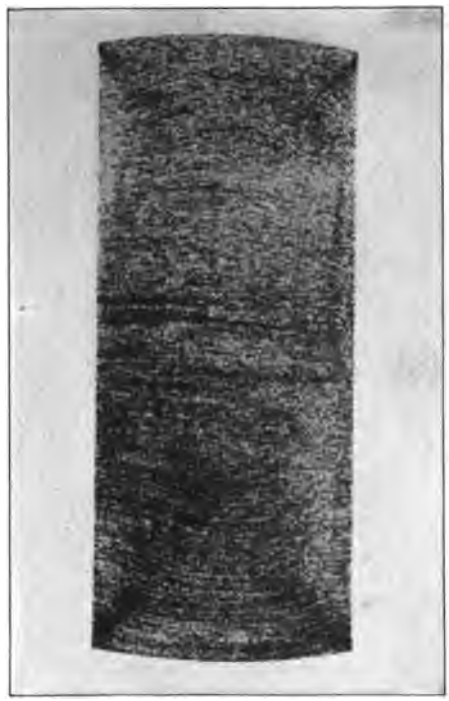
PHOTOGRAPH NO. 21.

Segregation of phosphorus in cold-rolled shafting. Etched with iodine. (White areas.)



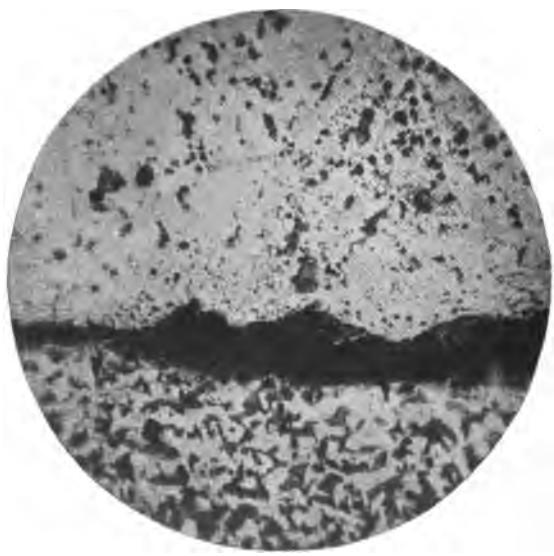
PHOTOGRAPH NO. 22.

Cross section of No. 21. Etched with nitric acid. (Dark streaks.)



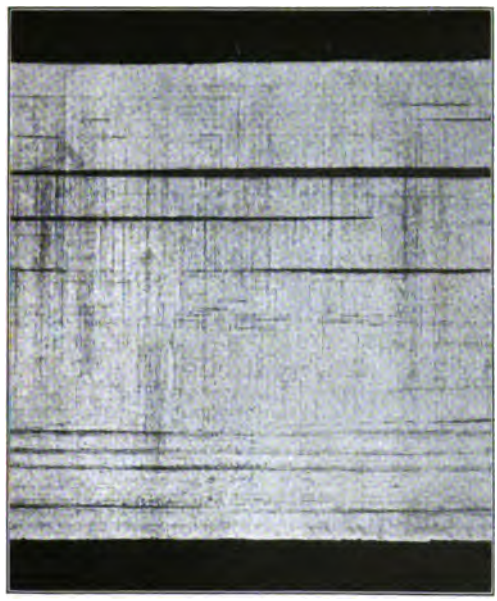
PHOTOGRAPH NO. 23.

Area of strained metal brought out by etching with copper ammonium chloride.



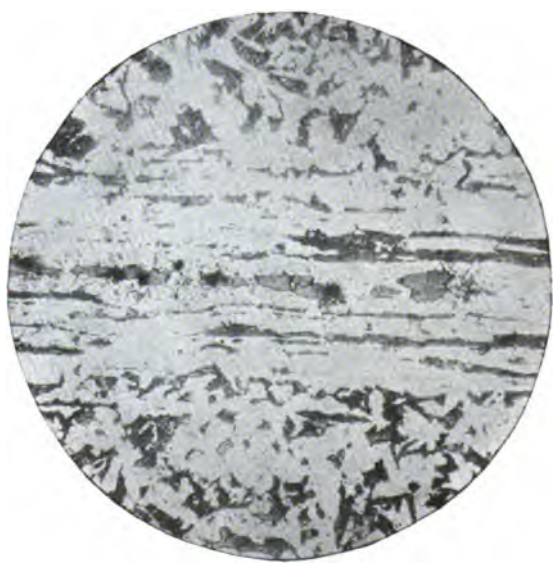
PHOTOGRAPH NO. 24. (X50.)

Crack, slag, and decarbonized area found on the base of a steel rail.



PHOTOGRAPH NO. 25.
Dark streaks in steel rail.

PHOTOGRAPH NO. 26.
Light streaks in steel rail.



PHOTOGRAPH NO. 27. (×50.)
Microstructure of light-colored streak in No. 26.

PHOTOGRAPH NO. 28. (X75.)

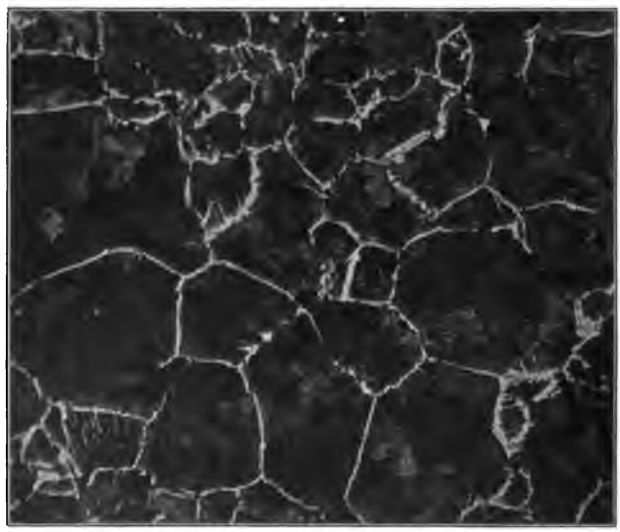
Microstructure of cast steel ingot as cast.

E. L.	39,000
T. S.	77,000
Elong	10.5
Cont	16.9

PHOTOGRAPH NO. 29. (X75.)

Microstructure of cast steel ingot forged to 1,450° F. (788° C.)

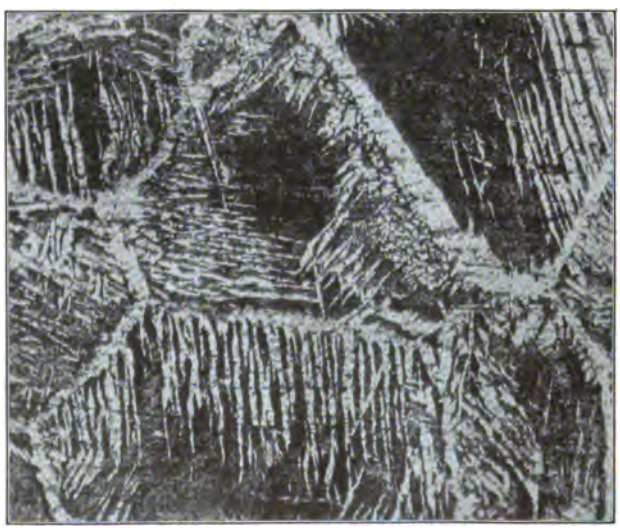
E. L.	50,500
T. S.	83,500
Elong	27.5
Cont	43.3



PHOTOGRAPH NO. 30. (×75.)
Coarse microstructure in gun steel.

PHOTOGRAPH NO. 31. (×50.)
Crystalline structure in cast steel.

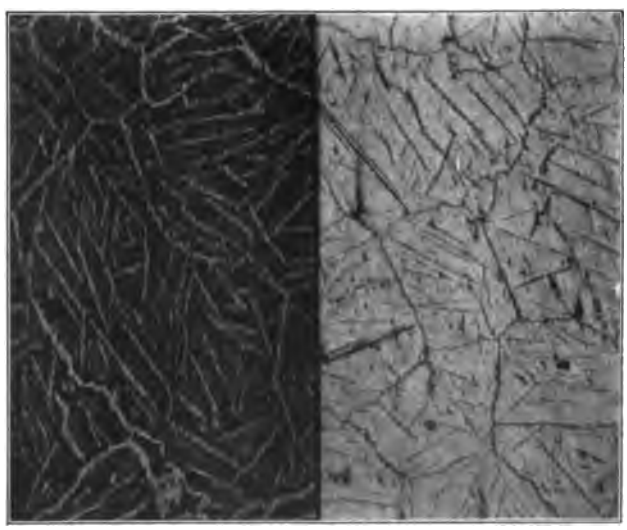
PHOTOGRAPH NO. 32. (X75.)
Microstructure showing incomplete heat treatment.



PHOTOGRAPH NO. 33. (X75.)
Microstructure of overheated steel.

PHOTOGRAPH NO. 34. (X500.)

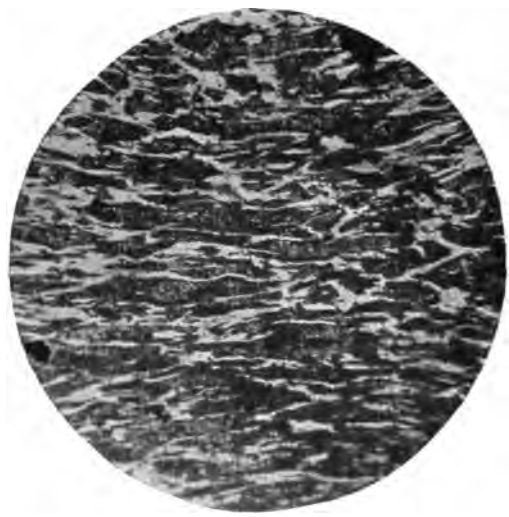
Microstructure of forging which had been originally martensitic, and in tempering this structure has not been completely eliminated.



PHOTOGRAPH NO. 35. (X65.)

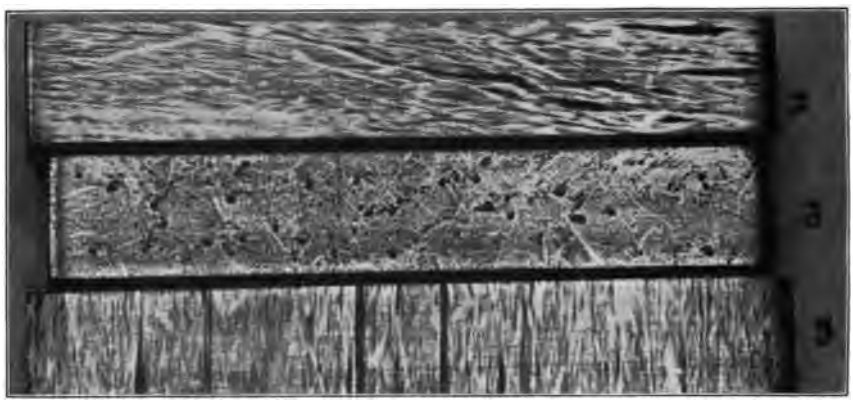
Microstructure in center of broken recoil spring, showing excess cementite indicating high carbon.

Left.	Right.
White lines are cementite etched with nitric-acid solution.	Dark lines are cementite etched with sodium-picrate solution.



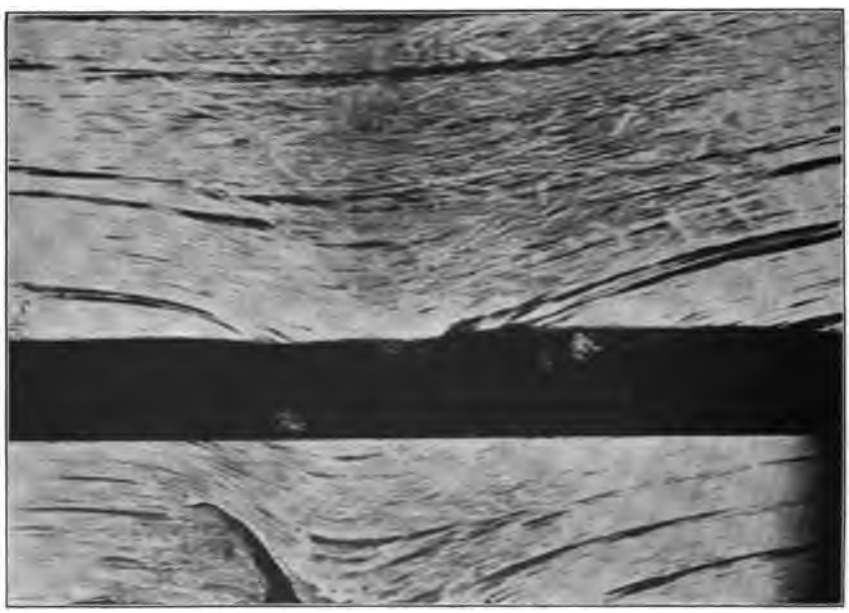
PHOTOGRAPH NO. 36. (X50.)
Microstructure of steel subjected to cold work, and showing distortion of grain.

PHOTOGRAPH NO. 37. CRACK IN 10-INCH RIFLE.



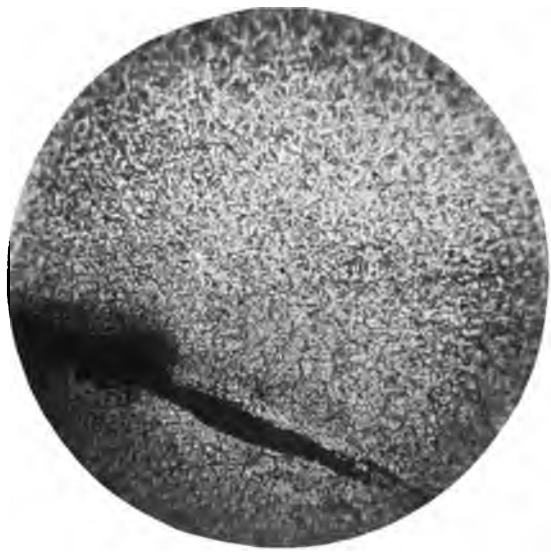
PHOTOGRAPH NO. 38.

Macrostructure of test bars of 10-inch rifle, showing surfaces cut longitudinal (5), radial (3), and tangential (2) to axis.



PHOTOGRAPH NO. 39.

Macrostructure in region of crack in 10-inch rifle.



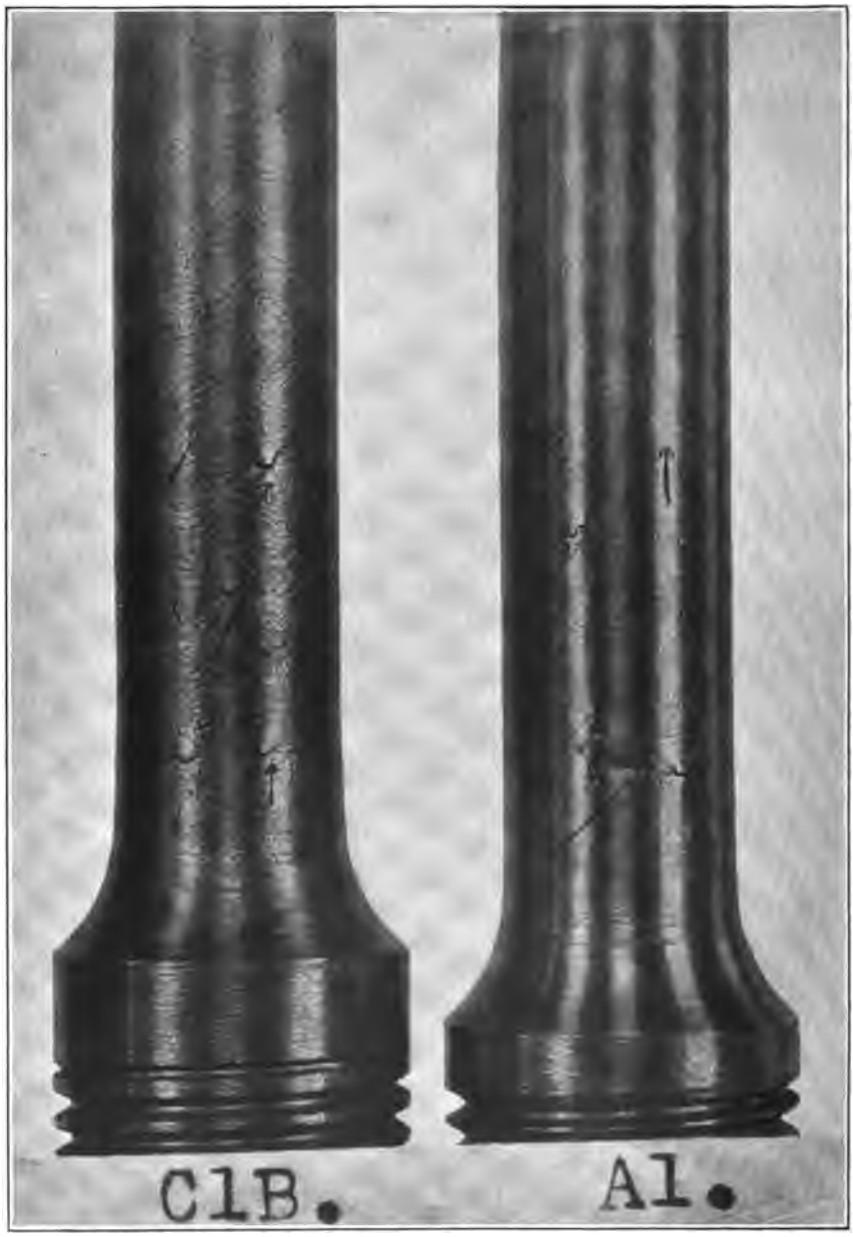
PHOTOGRAPH NO. 40. (×50.)
Crack and slag, with decarbonized area in 10-inch rifle.

PHOTOGRAPH NO. 41. (×50.)
Slag in 10-inch rifle. Unetched.

PHOTOGRAPH NO. 42. (X50.)
Slag in 10-inch rifle. Unetched.

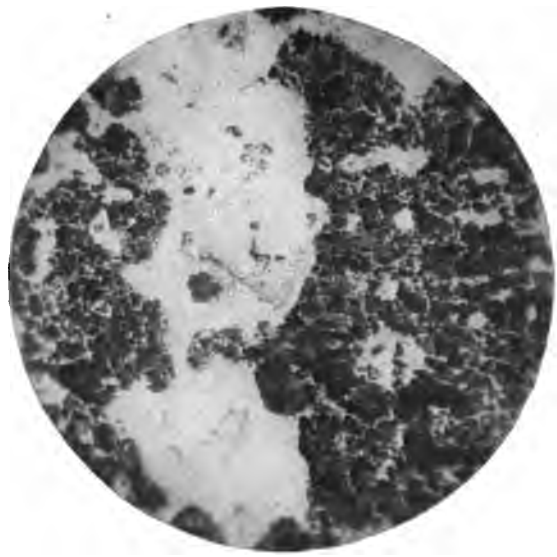
PHOTOGRAPH NO. 43. (X50.)
Slag and decarbonized area in 10-inch rifle.

PHOTOGRAPH NO. 44. (×50.)
Island of slag in decarbonized area in 10-inch rifle.

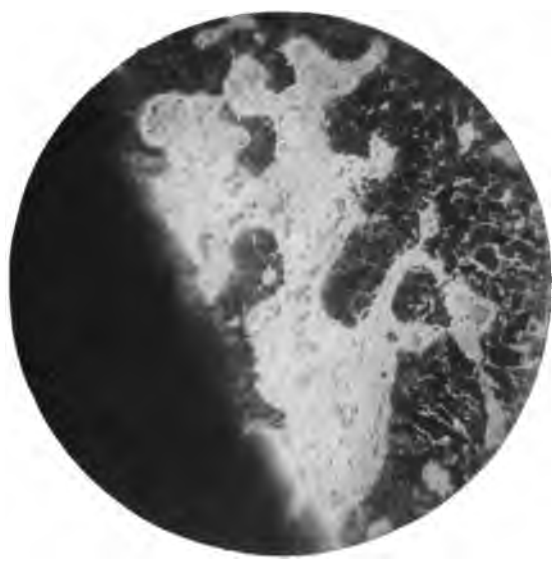


PHOTOGRAPH NO. 45.

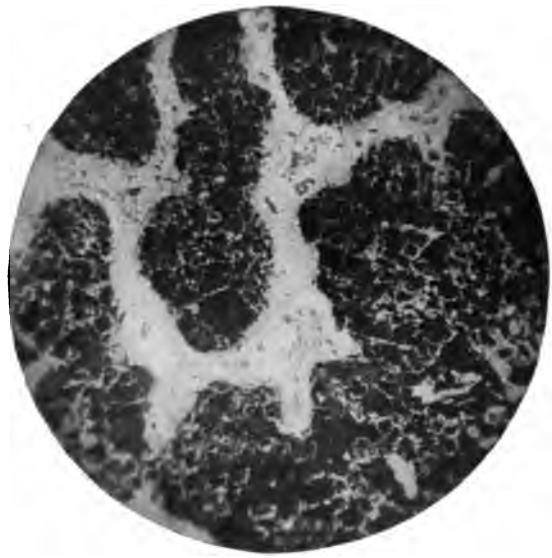
14-inch gun lever test bar specimens, showing incipient cracks.



PHOTOGRAPH NO. 46. (×50.)
14-inch gun lever. Segregated ferrite with slag inclusions.
(White.)



PHOTOGRAPH NO. 47. (×50.)
14-inch gun lever. Segregated ferrite on edge of test piece.
Slag inclusions.



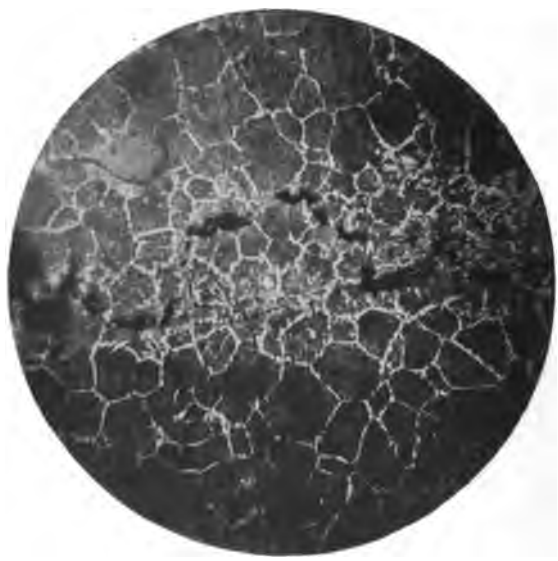
PHOTOGRAPH NO. 48. (×50.)
14-inch gun lever. Segregated ferrite with slag inclusions.
(White.)

PHOTOGRAPH NO. 49. (×50.)
14-inch gun lever. Segregated ferrite with slag inclusions.

PHOTOGRAPH NO. 50. (X50.)
14-inch gun lever. Segregated ferrite and crystalline structure.

PHOTOGRAPH NO. 51. (X50.)
14-inch gun lever. Crystalline structure.

PHOTOGRAPH NO. 52.
Macrostructure of metal removed from 12-inch Navy gun.



PHOTOGRAPH NO. 53. (×50.)
12-inch Navy gun. Microstructure showing slag and fissures.

PHOTOGRAPH NO. 54. (×50.)
12-inch Navy gun. Slag in unetched specimen.

PHOTOGRAPH NO. 55. (×50.)
12-inch Navy gun. Same area as No. 54, etched with alcoholic nitric acid.

REPORT OF PROGRESS ON INVESTIGATION OF THE RELATIVE MERITS OF VARIOUS AGENTS FOR THE DEOXIDATION OF STEEL.

MADE BY

H. M. BOYLSTON

AT WATERTOWN ARSENAL IN CONNECTION WITH AN ANDREW CARNEGIE RESEARCH SCHOLARSHIP GRANTED BY THE IRON AND STEEL INSTITUTE OF LONDON, ENGLAND.

This report covers work performed between May, 1914, and October 1, 1915.

INVESTIGATION OF DEOXIDIZERS OF STEEL.

On January 31, 1914, Mr. H. M. Boylston, of Cambridge, Mass., applied for permission to carry out at Watertown Arsenal a portion of the work in connection with a research on "The relative merits of various agents for the deoxidization of steel," and requested that arrangements be made for the cooperation with him of the authorities of the arsenal. It was obvious that the subject of the research was of prime importance to the Ordnance Department as affecting its foundry practice, and the Chief of Ordnance authorized the work to be done.

A large portion of the work in connection with this research was carried out at this arsenal during this fiscal year, and Mr. Boylston has submitted a report of progress which is inserted herein as being of interest and value.

INVESTIGATION OF THE RELATIVE MERITS OF VARIOUS AGENTS FOR THE DEOXIDATION OF STEEL.

Few problems in the steel industry have been investigated more than the question of making sound ingots or castings, and the means of preventing blowholes has been the subject of much study in this connection. Whether made by the crucible, the Bessemer, or the open-hearth process, steel when cast has always contained blowholes to some extent. Various devices have been used and numerous kinds of "physic" added to prevent the occurrence of these cavities, which exist sometimes near the surface and sometimes near the center of the cast metal, rendering it in most cases of little value for castings and for large ingots except where the carbon content is quite low. The cause of these cavities has generally been associated in most minds with oxides of iron and of other elements, and materials used for their prevention have therefore come to be known as deoxidizers.

In a later report the author will include a digest of previous work done along this line, the results of which have been published. Most of it has been done in a haphazard fashion, although several valuable papers have been based on scientific research. These are comparatively recent, however, and refer rather to the chemical analysis of the gases existing in molten steel than to any attempt to find a remedy for preventing the formation of blowholes.

Most researches also have compared ordinary steel (made with manganese additions, either with or without silicon) with similar steel to which aluminum has been added. Other researches have compared similar steel with steel to which titanium has been added, etc.

It seemed desirable, therefore, to compare directly the effect of the more ordinary so-called deoxidizers in order to furnish a scientific

basis, first for detailed experiment in any particular case, and second for a rough approximation of the relative merits of different agents. The fact that all of the substances used for this purpose have a great affinity for oxygen is another piece of evidence showing that most metallurgists have recognized the influence of oxygen on blowhole formation.

The author realizes that the terms deoxidizer and deoxidation may be open to criticism. The terms solidifier and degasifier have suggested themselves, but although substances other than oxygen probably play considerable part in the formation of blowholes, he believes that the term deoxidation is so well established in its special meaning that it forms the best word to use in the subject of this research.

OBJECT.

The principal aim of this research is to ascertain the effect of the various commercial deoxidizers in rendering steel sound (especially as regards blowholes) and in removing oxides of iron. The prevention of piping is not considered here except incidentally, since this defect can generally be prevented by physical means, such as keeping hot the top of the ingot, fluid compression, etc. It should of course be borne in mind that a reagent may render an ingot or casting perfectly sound as regards blowholes while adding material in the way of by-products of deoxidation which would affect the physical properties of the metal. Hence the physical properties will be taken into account in this research.

CHOICE OF STEEL-MAKING PROCESS.

A Tropenas 2-ton converter was available for this work, and it was not easy to make arrangements for the use of any other type of furnace. The choice was therefore principally a practical one, for although a greater tonnage of open-hearth steel is made the Bessemer is the one which gives the most highly oxidized product, perhaps, of any of the usual processes, so that by exaggerating the oxidizing conditions by the use of this method, as well as by overblowing the metal, one is placed in a position where deoxidizing conditions can be studied more effectively. It should not be inferred, therefore, that the results obtained in these experiments should be directly applicable in detail to all methods of steel making, especially in regard to the proportion of deoxidizer added, but the author hopes that the results will point the way to similar work with other steel processes, notably the basic open hearth, which produces the largest tonnage of any, at least in the United States.

GENERAL PLAN.

It was decided that the effect of the various deoxidizers on raw converter metal should first be determined in order to select the proportion of each to be used for comparison with each other in the making of actual steel. Much thought was given to the selection of the proportions to be added. Where obtainable the advice of the manufacturer of the deoxidizer was followed fairly closely, and in all cases the advice of numerous well-known metallurgists and steel men

was used. It was finally decided to cast 72 ingots of raw metal (from the Tropenas converter) to which the various proportions of the different deoxidizers were to be added. Four proportions of each were used and the ingots were made in triplicate, the object being merely to determine which of the four gave the soundest ingot as measured by the density and the appearance of a section. Vertical sections would have been more valuable than transverse, but the cost made this impracticable. The second experiment included 15 ingots of commercial steel from one heat, to which were added the proportions of each deoxidizer which were found to give the best results in experiment 1. The ingots in experiment 2 were subjected to a more complete examination, tests being made for density, porosity, tenacity, ductility, etc., from both cast and forged metal after heat treatment.

All ingots were cast in the steel foundry at Watertown Arsenal under works conditions.

DETAILS OF PROCEDURE.

The first plans called for the use of steel (as opposed to raw converter metal) for experiment 1, and the plan was to add washed metal to bring up the carbon content.

Several preliminary experiments were therefore made to find out what deoxidizing or solidifying effect the washed metal itself might have, so that it could be decided in which order the deoxidizer and the recarburizer should be added. Some 12 ingots weighing about 150 pounds each were poured, two of these being (1) raw converter metal, and the other 10 having added to them (2) aluminum only, (3) washed metal only, (4) aliminum and then washed metal, (5) washed metal and then aluminum. In most cases more than one ingot was made with a given addition.

In figures 1 to 4, inclusive, are shown photographs in vertical section, about one-half natural size, of ingots representing the first four of these classes after cropping 25 per cent of their length, and in figures 5 to 8 inclusive, are shown photographs, about full size, of the same ingots in transverse section at the point of cropping.

The chemical analysis for carbon in these ingots is given below.

TABLE 1.—*Carbon content of preliminary ingots.*

Ingot No.	Illustration.	Per cent of carbon.
1	Figures 1 and 5...	0.184
2	Figures 2 and 6...	.170
3	Figures 3 and 7...	.33
4	Figures 4 and 8...	.314

It is interesting to note the comparative solidity of the raw converter metal cast without additions, figures 1 and 5, but it must be remembered that this metal contained about 0.184 per cent carbon, and could therefore hardly have been overblown as much as was intended. This is checked by the casting notes, which state that metal was very slightly overblown. The additions of aluminum, either alone or with washed metal added later, figures 2 and 6, 4 and 8, produced a deep pipe but no blow holes, whereas when washed metal alone was added an extremely spongy ingot was produced.

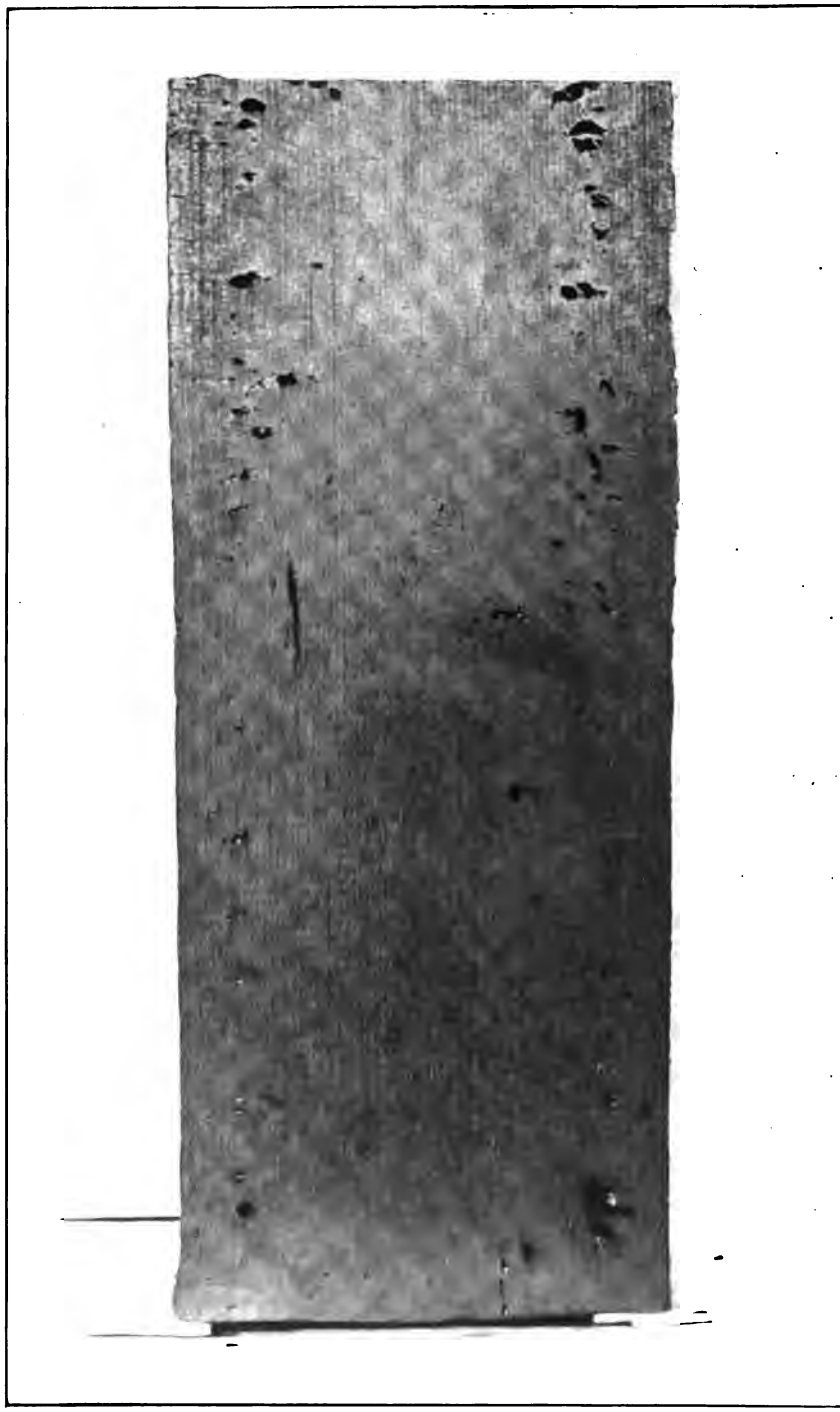


FIG. 1.—RAW CONVERTER METAL. VERTICAL SECTION.

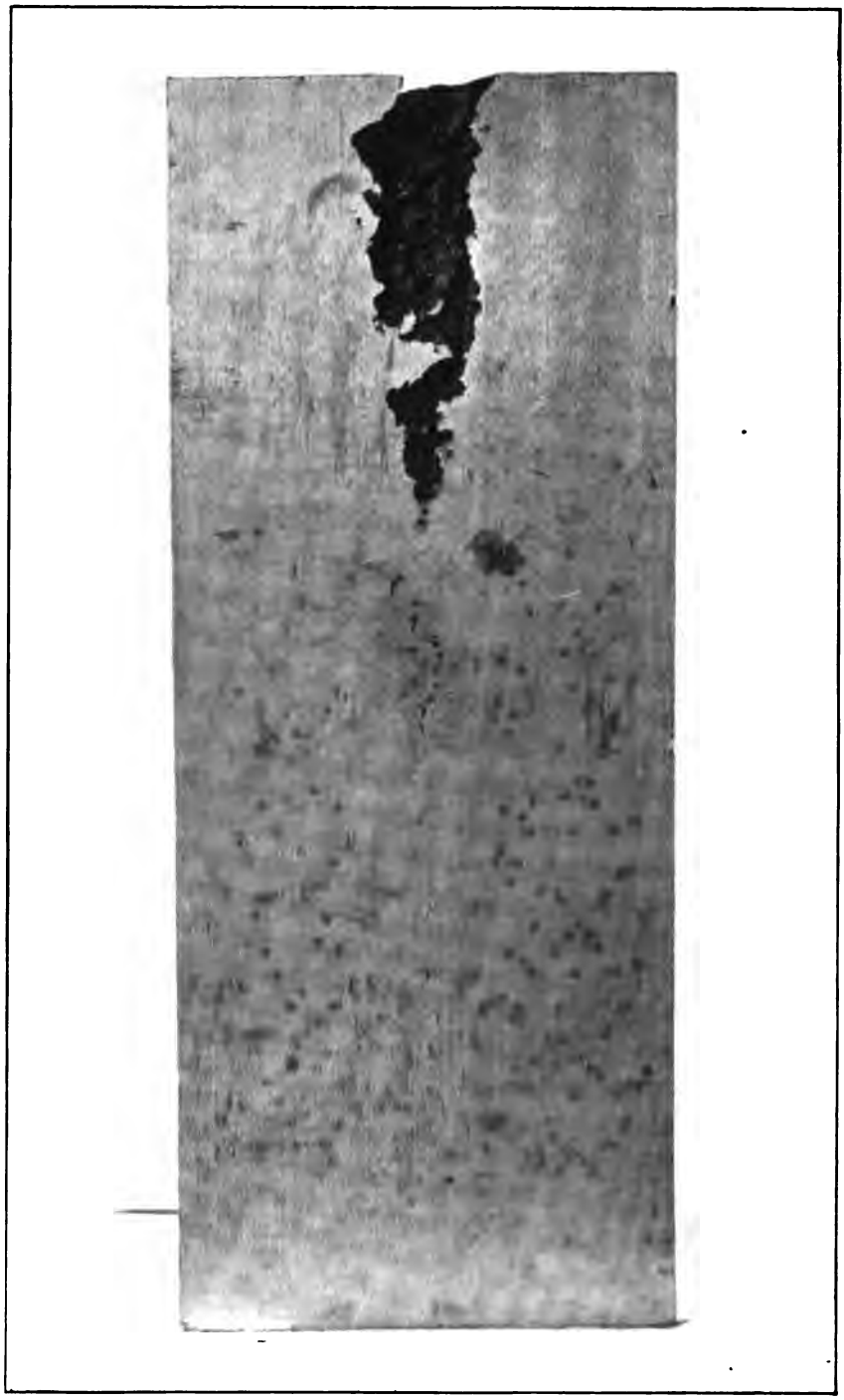


FIG. 2.—RAW CONVERTER METAL WITH 0.05 PER CENT Al. VERTICAL SECTION.

FIG. 3.—RAW CONVERTER METAL WITH ABOUT 18 POUNDS WASHED METAL CONTAINING 3.46 PER CENT C. VERTICAL SECTION.

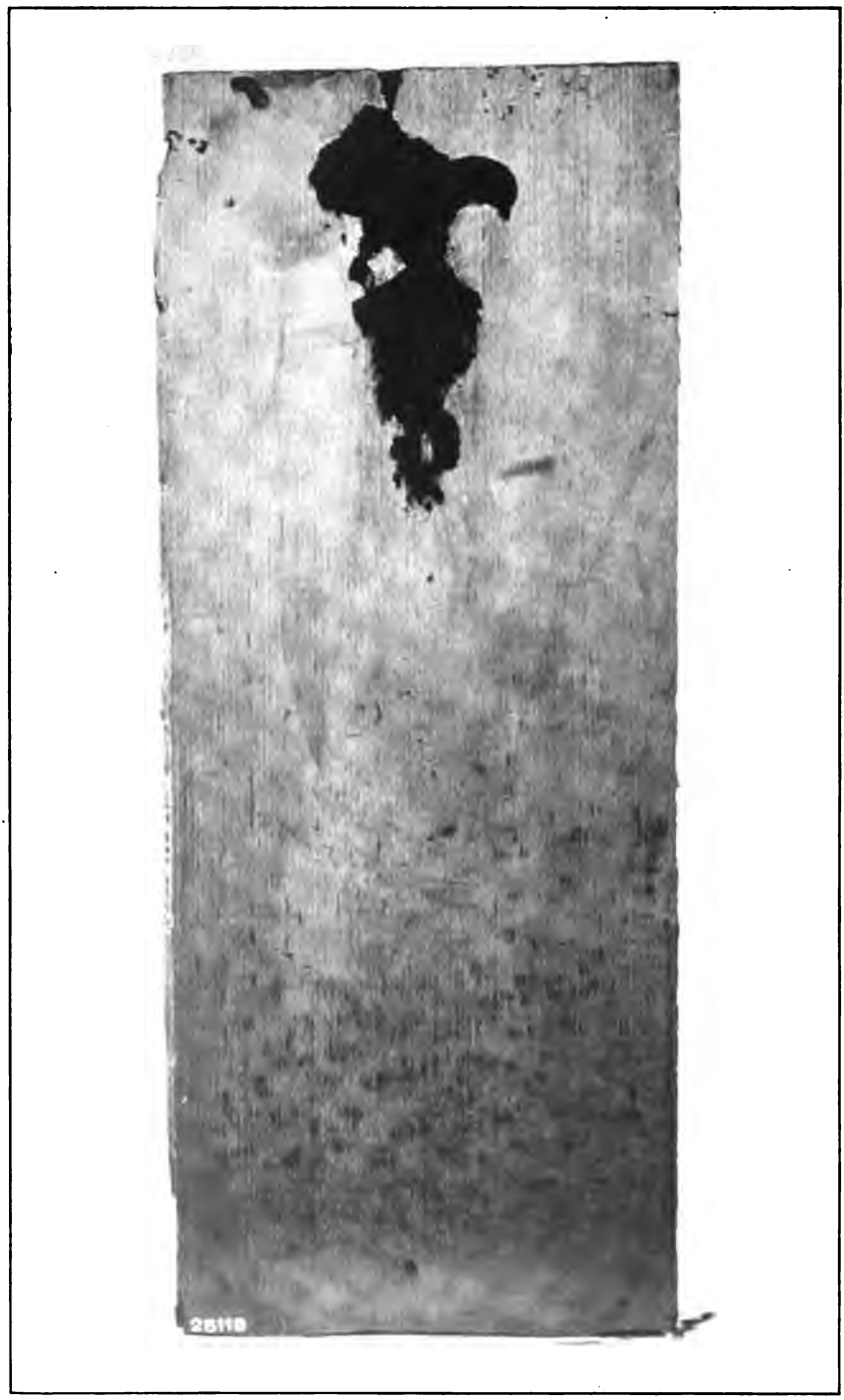


FIG. 4.—RAW CONVERTER METAL WITH 0.05 PER CENT Al AND ABOUT 18 POUNDS WASHED METAL CONTAINING 3.46 PER CENT C. VERTICAL SECTION.

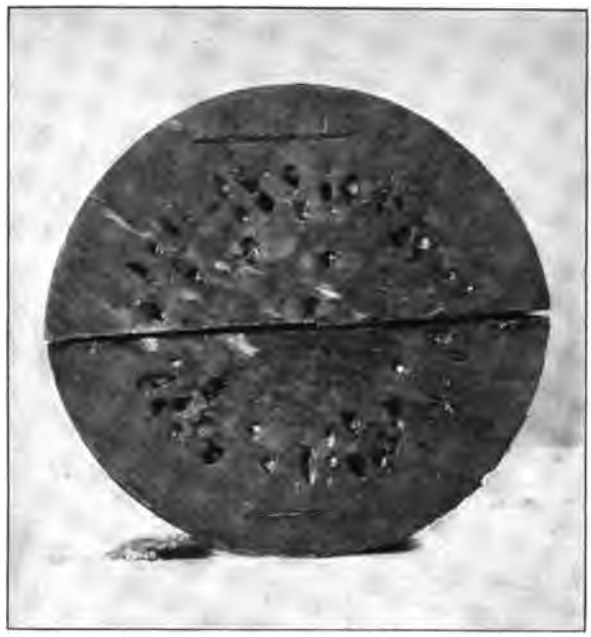


FIG. 5.—RAW CONVERTER METAL.
Transverse section at cropping point.

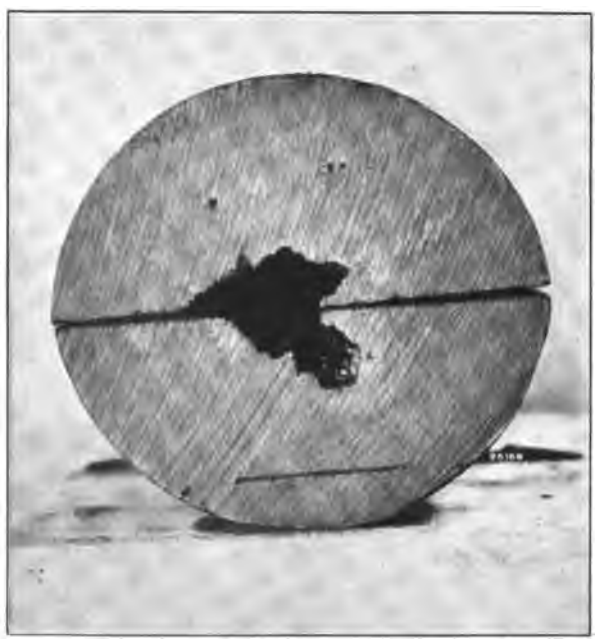


FIG. 6.—RAW CONVERTER METAL WITH 0.05 PER CENT Al.
Transverse section at cropping point.

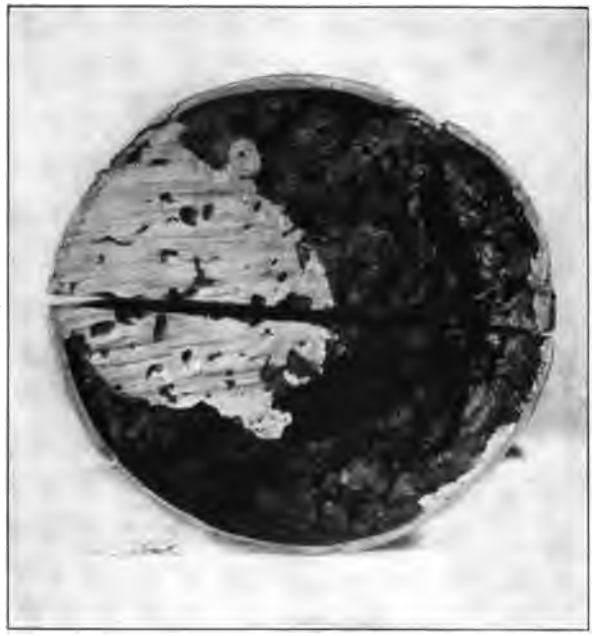


FIG. 7.—RAW CONVERTER METAL WITH ABOUT 18 POUNDS WASHED METAL CONTAINING 3.46 PER CENT C.

Transverse section at cropping point.

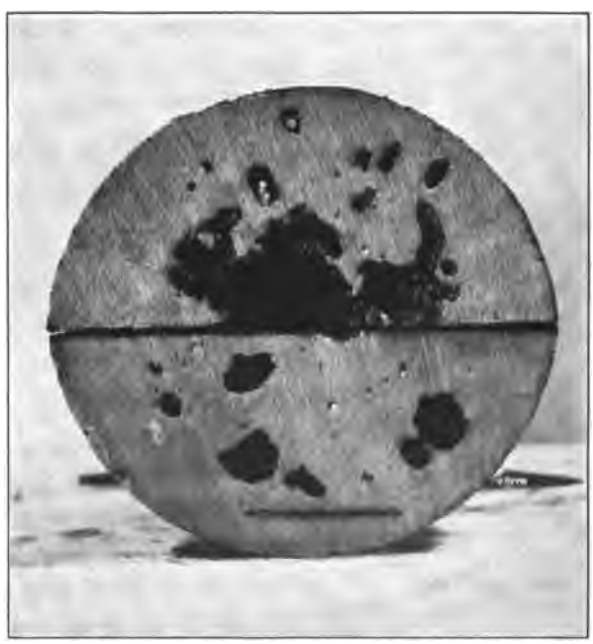


FIG. 8.—RAW CONVERTER METAL WITH 0.05 PER CENT Al AND ABOUT 18 POUNDS WASHED METAL CONTAINING 3.46 PER CENT C.

Transverse section at cropping point.

Class 5 is represented by figures 9 and 10. This ingot is fairly sound, but chemical analysis showed a carbon content of 1.35 per cent. The reason for such high carbon is unknown, but it doubtless accounts for the relative soundness. Several chemical analyses were made in various parts of the ingots and all the results showed over 0.90 per cent carbon. Microscopical examination from a section of this ingot representing metal from the center to the outside about half way down the ingot confirms the chemical analysis, the carbon being about 1.30 per cent in most places, and over 0.90 per cent at every point. The only reasonable explanation for this peculiar result is that there was some mistake made in weighing the additions.

The preliminary ingots suggest that it might be well to make an experiment with commercial steel, adding the deoxidizers before making the usual additions of carbon, manganese, and silicon, but this was omitted from the present research.

It was finally decided to perform experiment 1 with raw metal instead of recarburized metal so that a direct measure might be obtained of the deoxidizing and solidifying effect of the additions under test.

Proportion of ferro-carbon titanium.—In order to determine what should be the largest proportion of ferro-carbon titanium to be added and whether the additions should be preheated, three preliminary ingots were poured, the first being plain converter metal to check the previous results, the second containing about 4 pounds of 15 per cent ferro-carbon titanium added in very small pieces but not preheated, while to the third was added the same amount of 15 per cent ferro-carbon titanium which had been preheated to redness using a smoky oil flame. The intention was to add 0.3 per cent metallic titanium. Ingot No. 1 checked the previous results with plain converter metal very closely. In ingot No. 2 there was a considerable quantity of frozen material left in the hand ladle, and in both ingots Nos. 2 and 3 most of the ferro-carbon titanium floated to the top and was not absorbed. This was verified by microscopic examination. It was decided to use 0.1 per cent titanium in the form of the 15 per cent alloy as the maximum, and that with this smaller amount it need not be preheated. It should be added here that most of the published results where titanuim has been used in steel mention 0.1 per cent titanium or less as the addition. The amount recommended by the manufacturers for commercial use is also 0.1 per cent Ti.

EXPERIMENT 1.

The steel was cast in three heats, 24 ingots to a heat.

The converter metal, after being somewhat overblown, was slagged off and poured into preheated clay-lined crucibles, which served as hand ladles. The additions had been carefully weighed out previously to the nearest half ounce in paper bags.

Molds.—These were of sand carefully baked and arranged in two large flasks for convenience. The dimensions of the molds were such as to accommodate an ingot 20 inches long by 6 inches in diameter. The molds were made by skilled molders according to the usual work's practice at the arsenal.

Casting.—Cupola metal in sufficient quantity was blown, slagged off, and poured by the men employed for this purpose at the arsenal,

and a large squad was used in order to handle the ladles rapidly. The steel was poured from the large ladle into the hand ladles by tilting and the proper amount of metal was ascertained by filling the ladle to a certain mark made previously. The endeavor was to have the ingots all of the same size as near as possible. On account of the small size of ingot, it was found impracticable to weigh the metal each time for fear of sculling. The deoxidizers were all weighed and added to the metal by the author.

Table 2 gives the records of the heats. It was attempted to hold the metal in the crucible for two minutes after making the addition, but it was soon found that this was impracticable and it will be seen from the table that most of the castings were held from one-half to one minute after the additions were made.

TABLE 2.—*Heat records in experiment 1.*

Ingot No.	Time into hand ladle.	Time of holding in hand ladle.	Temperature of pouring.	Remarks.
		m. s.	° *C.*	
1	11.28 a. m.....	1 23	1,560	First blow (heat A): Blown at 11.07.35, overblown at 11.07.48, down at 11.08, into ladle 11.10.50, scull removed 11.34.40, began pouring 11.36.30, chemist's cup sample taken 11.39.40.
2	11.29 a. m.....	1 30	1,375	
3	11.33 a. m.....	1 27	1,388	
4	11.34 a. m.....	2 03	1,375	
5	11.37 a. m.....	1 08	1,375	
6	11.39 a. m.....	1 02	1,382	
7	11.42 a. m.....	1 03	1,365	
8	.....	59	1,365	
9	.....	48	1,355	
10	11.44 a. m.....	48	1,365	
11	11.47 a. m.....	45	1,365	
12	.....	46	1,355	
13	11.50 a. m.....	51	1,340	
14	.....	45	1,340	
15	11.52 a. m.....	47	1,340	
16	.....	49	1,330	
17	11.54 a. m.....	55	1,340	
18	11.54 a. m.....	50	1,330	
19	11.57 a. m.....	37	1,340	
20	11.57 a. m.....	30	1,330	
21	11.59 a. m.....	29	1,330	
22	12.00 m.....	33	1,330	
23	12.02 p. m.....	25	1,330	34 minutes to cast 23 ingots.
24	.....	.....	.....	Lost; too cold.
25	1.30 p. m.....	46	1,355	Second blow (heat B): Blown at 1.20, into ladle 1.23.30, sculled 1.26.20, began pouring 1.28.
26	1.31 p. m.....	47	1,355	
27	1.31 p. m.....	58	1,355	
28	1.31 p. m.....	45	1,355	
29	1.33 p. m.....	1 8	1,355	
30	.....	48	1,355	
31	.....	45	1,355	
32	1.35 p. m.....	46	1,355	Spilled.
33	.....	55	1,355	
34	.....	1 15	1,365	
35	1.39 p. m.....	1 30	1,365	
36	.....	48	1,340	Scull on top of hand ladle.
37	.....	47	1,340	
38	.....	48	1,340	
39	1.42 p. m.....	43	1,330	12 minutes to cast 15 ingots.
40	.....	48	1,330	
41	.....	45	1,330	
42	.....	3 02	1,330	
43	Held in mold...	.....	1,330	
44	.....do.....	.....	1,330	
45	.....do.....	.....	1,330	
46	.....do.....	.....	1,330	
47	.....do.....	.....	1,330	
48	.....do.....	.....	1,330	

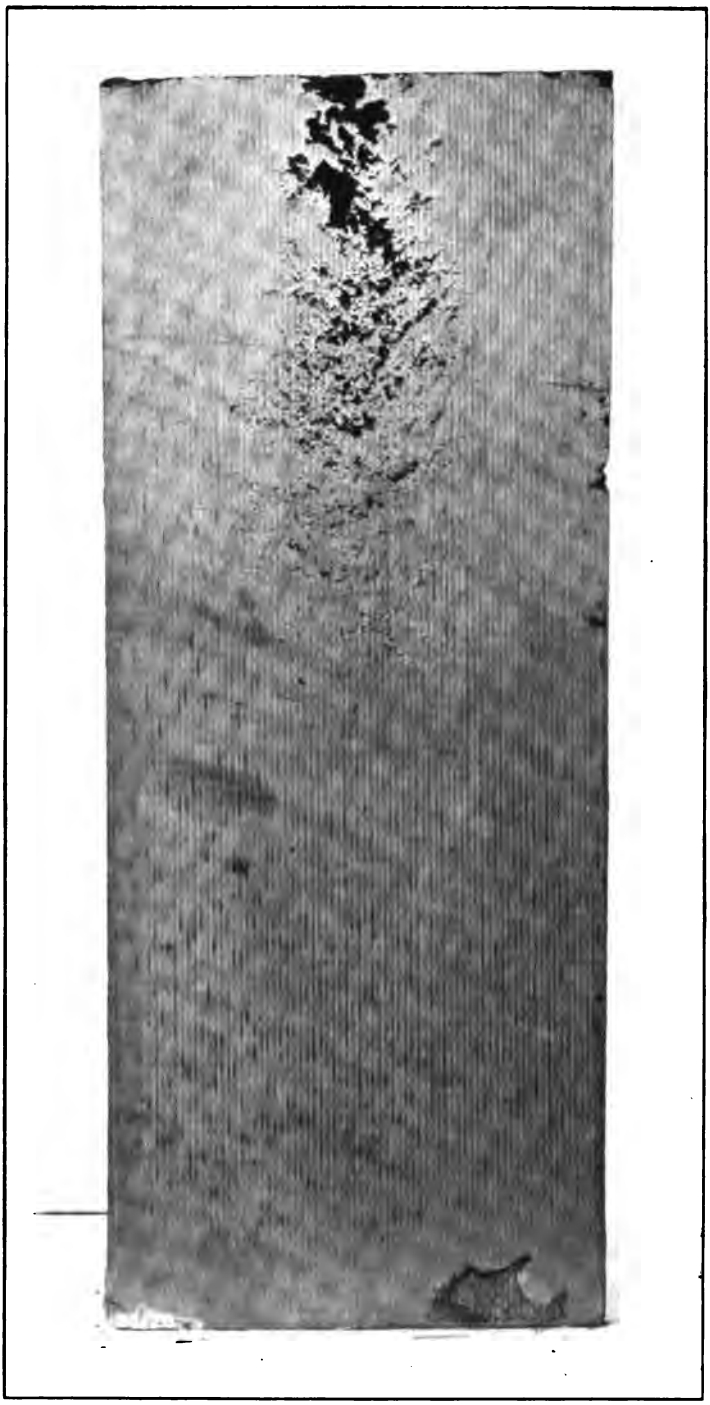


FIG. 9.—RAW CONVERTER METAL WITH WASHED METAL AND ABOUT 0.05 PER CENT Al. VERTICAL SECTION.

FIG. 10.—RAW CONVERTER METAL WITH WASHED METAL AND ABOUT 0.05 PER CENT Al.
Transverse section at cropping point.

TABLE 2.—*Heat records in experiment 1*—Continued.

Ingot No.	Time into hand ladle.	Time of holding in hand ladle.	Temperature of pouring.	Remarks.
		m. s.	° *C.*	
49	2.28 p. m.	43	1,330	Third blow (heat C): Blown at 2.19.40, overblown at 2.20.04, down at 2.20.30, into ladle 2.22.30, scull removed 2.26.10, began pouring 2.27.40.
50	.....	53	1,340	
51	2.30 p. m.	48	1,335	
52	.....	44	1,335	
53	2.32 p. m.	43	1,340	
54	.....	43	1,330	
55	2.33 p. m.	46	1,335	
56	.....	45	1,340	
57	2.34 p. m.	47	1,340	Hand ladle dropped.
58	.....	1 14	1,340	
59	.....	45	1,340	
60	.....	48	1,340	
61	2.39 p. m.	47	1,350	
62	.....	46	1,350	13 minutes to cast 15 ingots.
63	2.41 p. m.	2 5	1,340	Sputtered in hand ladle; refilled after 1 minute 10 seconds.
64	.....	1 48	1,340	
65	.....	44	1,330	
66	.....	45	1,330	
67	.....	43	1,350	
68	.....	48	1,350	
69	Held in mold	.....	1,340	
70	.....do	.....	1,325	
71	.....do	.....	1,340	
72	.....do	.....	1,340	

The temperatures were taken with a Holborn-Kurlbaum optical pyrometer by an experienced operator.

Table 3 gives the chemical analysis of the various deoxidizers used. Ferromagnesium and ferrovanadium were considered when planning the experiment, but the former is so expensive as to be limited to very high-grade steels, and ferro-vanadium is also expensive and is not now advocated as a deoxidizer by the principal manufacturers, who state that, although ferrovanadium has some deoxidizing power, their instructions to users call for its addition under conditions where it can not easily be oxidized, basing their claim to advantage on its effect on the physical properties, thus making what is practically an alloy steel, although the proportions of vanadium used are generally very small. These two materials were therefore omitted.

TABLE 3.—*Chemical analysis of deoxidizers.*

Deoxidizer.	C.	Mn.	Si.	S.	P.	Al.	Ti.	Fe.
	Per ct.	*Per ct.*	*Per ct.*	*Per ct.*	*Per ct.*	*Per ct.*	*Per ct.*	*Per ct.*
Ferromanganese	6.55	79.65	0.908	0.024	0.185	.....	.....	.....
Ferrosilicon	.16	.....	56.0	.....	.....	.....	.....	.....
Ferrocarbon-titanium	5.92	.....	2.10	.....	.....	None.	14.32	.....
Carbonfree ferrotitanium	.....	.....	1.30	.....	.....	7.61	24.0	.....
Aluminum	.....	.....	.87	.....	.....	[1] 99.08	.....	0.05

[1] By difference.

Proportions of deoxidizers used.—In Table 4 are given the records of the various proportions of deoxidizers used. It will be noted that in the case of aluminum, additions were made in the mold in some cases as well as in the ladle.

TABLE 4.—*Proportions of deoxidizers.*

HEAT A.

Ingot No.	Additions.	Additions in form of—	Weight of deoxidizer.		
			Calculated.	Weighed.	Per ton calculated.
			Ounces.	*Ounces.*	*Ounces.*
1	0.03 per cent Ti	15 per cent ferro-carbon-titanium.	5.4	5½	62.5
2					
3	0.045 per cent Ti		8.1	8	100
4					
5	0.06 per cent Ti		10.7	10½	131
6					
7	0.10 per cent Ti		17.9	18	225
8					
9	0.01 per cent Ti	25 per cent carbon-free ferro-titanium, pea size.	1.1	1	12.5
10					
11	0.02 per cent Ti		2.2	2	25
12					
13	0.03 per cent Ti		3.2	3	37.5
14					
15	0.10 per cent Ti		10.7	10½	131
16					
17	0.20 per cent Si	50 per cent ferro-silicon	9.2	9	113
18					
19	0.30 per cent Si		13.7	13½	169
20					
21	0.40 per cent Si		18.3	18½	231
22					
23	0.50 per cent Si		22.9	23	288
24					

HEAT B.

25	0.50 per cent Mn	80 per cent ferro-manganese	16.1	16	200
26					
27	0.75 per cent Mn		24.1	24	300
28					
29	1.00 per cent Mn		32.2	32	400
30					
31	1.25 per cent Mn		40.2	40	500
32					
33	0.05 per cent Al	94–98 per cent granulated aluminum.	1.3	1½	19
34					
35	0.10 per cent Al		2.6	2½	31
36					
37	0.20 per cent Al		5.2	5	63
38					
39	0.30 per cent Al		7.8	8	100
40					
41	0.05 per cent Al	94–98 per cent granulated aluminum.	1.3	1½	19
42					
43	0.10 per cent Al		2.6	2½	31
44					
45	0.20 per cent Al		5.2	5	63
46					
47	0.30 per cent Al		7.8	8	100
48					

HEAT C.

49	0.03 per cent Ti	15 per cent ferro-carbon-titanium.	5.4	5½	62.5
50	0.045 per cent Ti		8.1	8	100
51	0.06 per cent Ti		10.7	10½	131
52	0.10 per cent Ti		17.9	18	225
53	0.01 per cent Ti	25 per cent carbon-free ferro-titanium, pea size.	1.1	1	12.5
54	0.02 per cent Ti		2.2	2	25
55	0.03 per cent Ti		3.2	3	37.5
56	0.10 per cent Ti		10.7	10½	131
57	0.20 per cent Si	50 per cent ferro-silicon	9.2	9	113
58	0.30 per cent Si		13.7	13½	169
59	0.40 per cent Si		18.3	18½	231
60	0.50 per cent Si		22.9	23	288
61	0.50 per cent Mn	80 per cent ferro-manganese	16.1	16	200
62	0.75 per cent Mn		24.1	24	300
63	1.00 per cent Mn		32.2	32	400
64	1.25 per cent Mn		40.2	40	500

TABLE 4.—*Proportions of deoxidizers*—Continued.

HEAT C—Continued.

Ingot No.	Additions.	Additions in form of—	Weight of deoxidizer.		
			Calculated.	Weighed.	Per ton calculated.
			Ounces.	*Ounces.*	*Ounces.*
65	0.05 per cent Al	94–98 per cent granulated aluminum.	1.3	1½	19
66	0.10 per cent Al		2.6	2½	31
67	0.20 per cent Al		5.2	5	63
68	0.30 per cent Al		7.8	8	100
69	0.05 per cent Al	94–98 per cent granulated aluminum.	1.3	1½	19
70	0.10 per cent Al		2.6	2½	31
71	0.20 per cent Al		5.2	5	63
72	0.30 per cent Al		7.8	8	100

NOTE TO TABLE 4.—In column 2 are given the additions as calculated in percentages of the deoxidizing element (Ti, Al, Mn, etc.). In column 4 these percentages have been calculated in weights of the actual deoxidizer, using the actual chemical analyses given in Table 3; while column 5 gives the weights of deoxidizer actually used. The scales used in weighing were accurate to one-half ounce. In the sixth column are given the weights of deoxidizer calculated in ounces per ton (from column 5) for the sake of comparison with large-scale experiments.

In heats A and B it will be noted that there are duplicate ingots for each addition poured in succession. All additions were made in the hand ladle except in the case of ingots 41 to 48, inclusive, and 69 to 72, inclusive (aluminum), where the additions were made in the mold. The hand ladles and the ferro-manganese were preheated, the latter in a reducing flame to prevent premature oxidation. It was thought that if the ferro-manganese was not preheated it would tend to freeze the metal.

It should be borne in mind in interpreting the results of this experiment that the ferro-carbon-titanium contains about 2 per cent of silicon, and the carbon-free ferro-titanium about 1.3 per cent silicon and 7.6 per cent aluminum. (See Table 3.) The castings were divided into three heats because of the mechanical difficulty of pouring more than 24 ingots from one heat (limited to about 5,000 pounds each). The arrangement of ingots was made to neutralize as far as possible any error due to difference in temperature or carbon content of the raw metal in the different heats.

Chemical analysis.—The expense of making complete chemical analyses of all the ingots in experiment 1 was prohibitive, but in Table 5 are shown analyses for carbon in ingots 10, 41, and 53, these being representative ingots from those series in which the additions contained no carbon. In this table also are given the chemical analyses of representative ingots from heat C, showing the loss of deoxidizing element in the respective cases. It is noteworthy that no titanium was found either in the case of ferro-carbon-titanium or of carbonless ferro-titanium. The ingots analyzed were chosen from those containing the proportions of deoxidizer giving the densest ingot and hence selected for experiment 2.

TABLE 5.—*Chemical analyses of selected ingots from experiment 1.*

Ingot No.	Approximate percentage deoxidizer added.	Heat No.	C.	Mn.	Si.	Ti.	Al.
			Per ct.	*Per ct.*	*Per ct.*	*Per ct.*	*Per ct.*
10	0.01 Ti	A	0.030	.....	.....	.....	.....
41	0.05 Al	B	0.043	.....	.....	.....	.....
53	0.01 Ti	C	0.040	.....	.....	.....	.....
52	0.10 Ti as Fe-C-Ti	C	0.100	.....	.....	None.	.....
56	0.10 Ti as Fe-Ti	C	0.091	.....	.....	None.	.....
59	0.40 Si	C	0.081	.....	0.424 0.415	.....	.....
61	0.50 Mn	C	0.114	0.40	.....	.....	.....
67	0.20 Al	C	0.107	0.02	0.055	.....	0.028

NOTE TO TABLE 5.—In both ingots where titanium was added all of it was lost. In ingot 61, where manganese was added, and allowing for the mnaganese in the converter metal (see analysis of ingot 67, to which only aluminum was added), there was a loss of about 0.12 per cent Mn, or about one-fourth of the manganese added, while in ingot 59, allowing for the silicon in the converter metal (see ingot 67), there was a very slight loss of silicon, and in ingot 67 more than four-fifths of the aluminum was lost. It is difficult to explain why ingots 56, 59, and 67 analyze from twice to three times as high in carbon as the raw converter metal, unless the aluminum and carbonless ferro-titanium did actually contain considerable carbon. The ferro-silicon used analyzed about 0.16 per cent carbon, which is too small to account for the increase in carbon in this case.

Relative density.—The relative density of every ingot in experiment 1 was determined by the displacement method.

Formula for relative density.—The derivation of the formula for relative density is as follows, the letters being also used in Table 6:

T = weight of empty tank = 27.22 pounds.
W1 = weight of (tank + water up to mark) = 106.60 to 106.84 pounds on various days.
W2 = weight of (tank + water to bring up to mark) with ingot in tank.
I = weight of ingot in air.
W2 + I = weight of (tank + water to mark + ingot).
W1 − W2 = W3 = weight of water displaced by ingot.

The volume of W3 is assumed as equal to the volume of the ingot. The same water was used for all weighings and, since relative density rather than the precise specific gravity was sought, the specific gravity of the water was not determined. The difference in temperature of the water proved to be a negligible factor, the temperature varying not more than 5° C. at a temperature about 20° C. In the worst case the error amounted to only 0.1 per cent of the weight of water displaced by the ingot, this being equal to about 0.01 pound, or about one-sixth of the maximum error possible in weighing.

$$\frac{I}{W3} = \text{relative density of ingot.}$$

Table 6 gives the weights of the ingots with their relative densities, the proportions of the deoxidizers used, and the average relative density of the three ingots containing like proportions of the same deoxidizer.

TABLE 6.—*Density of ingots in experiment 1.*

Ingot No.	Addition.	Heat No.	Weight of ingots.	Relative density.	Average relative density.
			Pounds.		
1	0.03 per cent Ti–C.	A	95.94	5.815	
2		A	104.25	6.632	6.510
49		C	98.44	6.388	
3	0.045 per cent Ti–C.	A	104.84	6.848	
4		A	98.31	6.355	6.674
50		C	104.11	6.813	
5	0.06 per cent Ti–C.	A	101.13	6.619	
6		A	101.38	6.609	6.823
51		C	110.19	7.241	
7	0.10 per cent Ti–C.	A	105.56	6.690	
8		A	101.50	6.599	6.823
52		C	114.92	7.152	
9	0.01 per cent Ti.	A	95.75	6.154	
10		A	93.88	6.069	6.229
53		C	100.06	6.464	
11	0.02 per cent Ti.	A	101.25	6.340	
12		A	94.00	5.980	6.387
54		C	104.08	6.925	
13	0.03 per cent Ti.	A	98.79	6.205	
14		A	99.97	6.372	6.235
55		C	101.00	6.129	
15	0.10 per cent Ti.	A	115.38	7.444	
16		A	113.41	7.031	7.287
56		C	113.81	7.424	
17	0.20 per cent Si.	A	113.63	7.213	
18		A	103.44	7.341	7.348
57		C	77.31	7.770	

TABLE 6.—*Density of ingots in experiment 1*—Continued.

Ingot No.	Addition.	Heat No.	Weight of ingots.	Relative density.	Average relative density.
			Pounds.		
19		A	90.35	7.173	
20	0.30 per cent Si.	A	124.50	7.950	7.637
58		C	116.72	7.787	
21		A	114.03	7.700	
22	0.40 per cent Si.	A	119.50	7.821	7.838
59		C	120.36	7.993	
23		A	69.75	7.75	
24	0.50 per cent Si.	A	Ingot not cast.		7.77
60		C	114.44	7.79	
25		B	88.25	7.077	
26	0.50 per cent Mn.	B	115.59	7.144	7.145
61		C	99.06	7.215	
27		B	112.38	7.208	
28	0.75 per cent Mn.	B	112.88	6.934	6.950
62		C	84.59	6.682	
29		B	105.94	6.875	
30	1.00 per cent Mn.	B	110.78	6.924	6.839
63		C	78.34	6.719	
31		B	72.88	6.961	
32	1.25 per cent Mn.	B	95.97	7.026	6.971
64		C	81.38	6.926	
33		B	103.5	6.774	
34	0.05 per cent Al.	B	113.88	6.914	6.963
65		C	95.98	7.200	
35		B	96.55	6.724	
36	0.10 per cent Al.	B	106.38	6.903	6.678
66		C	74.06	6.346	
37		B	119.69	7.979	
38	0.20 per cent Al.	B	123.08	7.915	7.935
67		C	97.38	7.912	
39		B	118.08	7.784	
40	0.30 per cent Al.	B	116.81	7.715	7.824
68		C	104.25	8.644	
41		B	87.66	6.417	
42	0.05 per cent Al.	B	54.75	7.242	6.989
69		C	82.88	7.309	
43		B	86.78	6.645	
44	0.10 per cent Al.	B	79.31	6.951	7.118
70		C	86.03	7.757	
45		B	85.34	6.364	
46	0.20 per cent Al.	B	62.28	6.023	6.806
71		C	102.16	8.031	
47		B	113.12	7.727	
48	0.30 per cent Al.	B	69.72	7.324	7.441
72		C	98.19	7.273	

NOTE TO TABLE 6.—A curious relation exists between the weight of the ingot and the relative density. In almost every case the greater the weight, the greater the relative density. The reason for the variation in the weights (which was intended to be 120 pounds in every case after cropping) is that some of the metal stuck in the hand ladles and could not be poured. The smallest ingot was No. 42, weighing 54.75 pounds (cropped). The heaviest ingot was No. 20 and it weighed 124.50 pounds (cropped).

The density of ingot No. 1 was ignored in the average because of a large cavity in the top of the ingot.

RESULTS.

It will be seen that in the majority of cases the relative densities are as constant as could be expected with the variation in pouring temperature, which could not be entirely avoided.

On the following chart are plotted the average relative densities. It will be noted that for the proportions used aluminum added in the ladle gives the densest ingots in general, while the general efficacy of the other deoxidizers is in the following order:

Silicon.
Aluminum in the mold.
Carbon-free ferro-titanium.
Ferro-manganese.
Ferro-carbon-titanium.

The curves cross each other somewhat, but the maximum of each curve is taken as the criterion. It will be noted that the smallest proportion of ferro-manganese gives the best results, further additions apparently chilling the metal. The curve for ferro-manganese starts to rise again, however, for the highest proportion used, and this will bear further investigation.

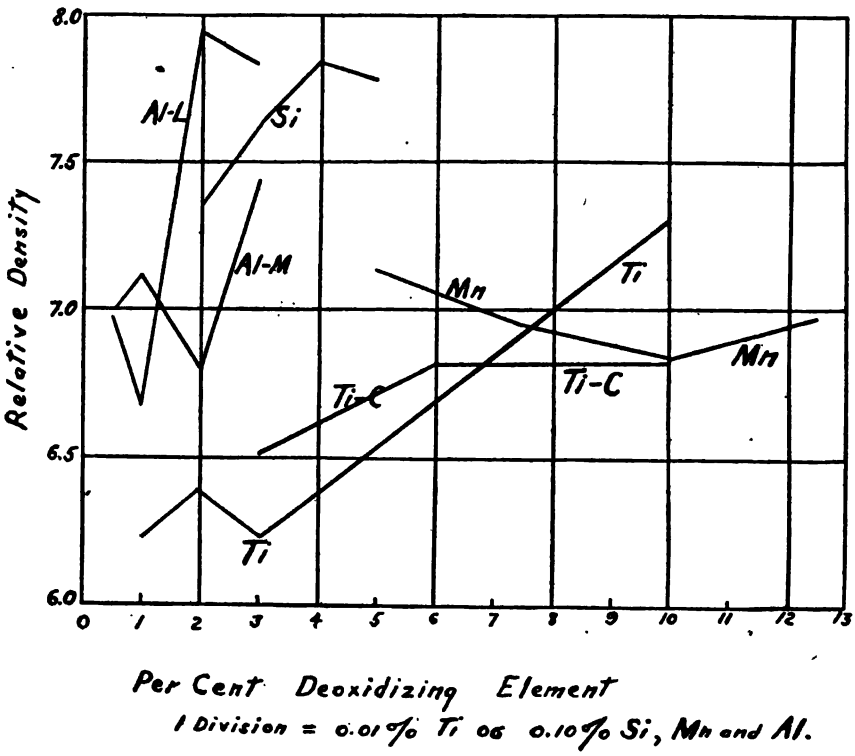


Chart 1. Diagram showing relative density of ingots of converter metal with various deoxidizers added.

Legend for chart.

Al–L = aluminum added in ladle.

Al–M = aluminum added in mold.

Si = ferro-silicon.

Ti = carbon-free ferro-titanium.

Ti–C = ferro-carbon titanium.

Mn = ferro-manganese.

The scale of relative densities has purposely been exaggerated to bring out more clearly the difference in relative density.

Photographs.—Photographs were taken of the cross sections of the cropped ingots at the point of cropping and the results are shown in figures 11 to 28. In general they are very consistent with the relative density figures. It will be noted that aluminum and silicon produces a small pipe, but few if any blow holes, except with the two lower proportions of deoxidizer; whereas both titanium alloys and ferro-manganese produce many blowholes, but little pipe if any, the number of blowholes decreasing as the titanium content is raised

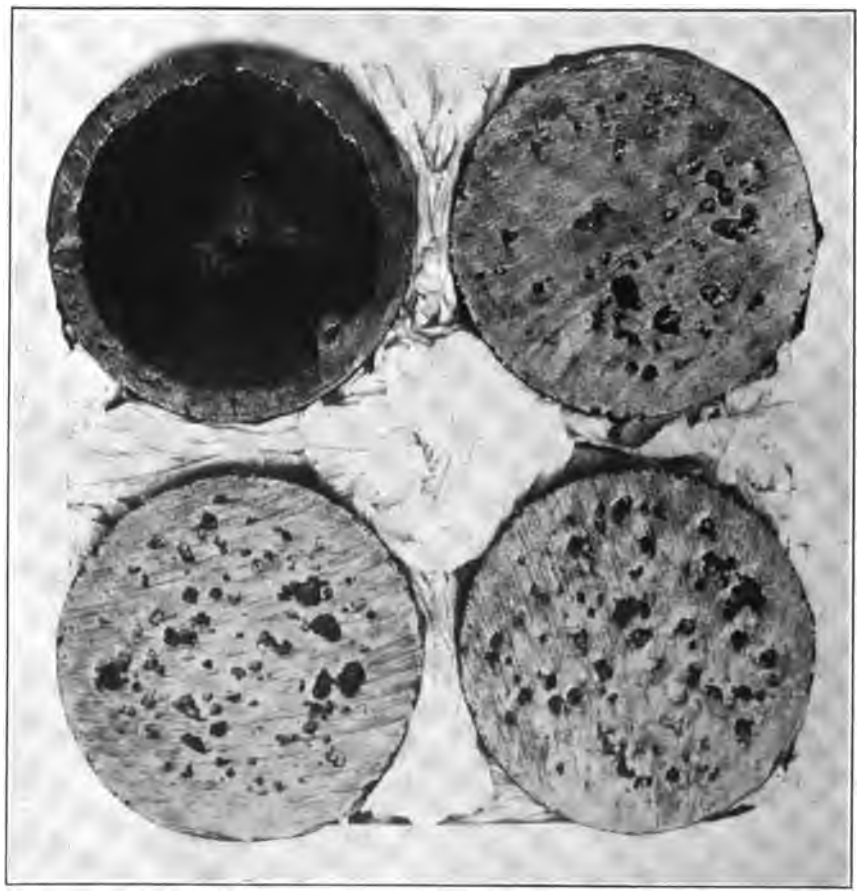


FIG. 11.—INGOTS 1 AND 2 WITH 0.03 PER CENT Ti. INGOTS 3 AND 4 WITH 0.045 PER CENT Ti.

Transverse section at cropping point. Addition used: 15 per cent ferrocarbon titanium.

FIG. 12.—INGOTS 5 AND 6 WITH 0.06 PER CENT Ti. INGOTS 7 AND 8 WITH 0.10 PER CENT Ti.

Transverse section at cropping point. Addition used: 15 per cent ferrocarbon titanium.

FIG. 13.—INGOTS 9 AND 10 WITH 0.01 PER CENT TI. INGOTS 11 AND 12 WITH 0.02 PER CENT TI.

Transverse section at cropping point. 25 per cent carbon-free ferrotitanium.

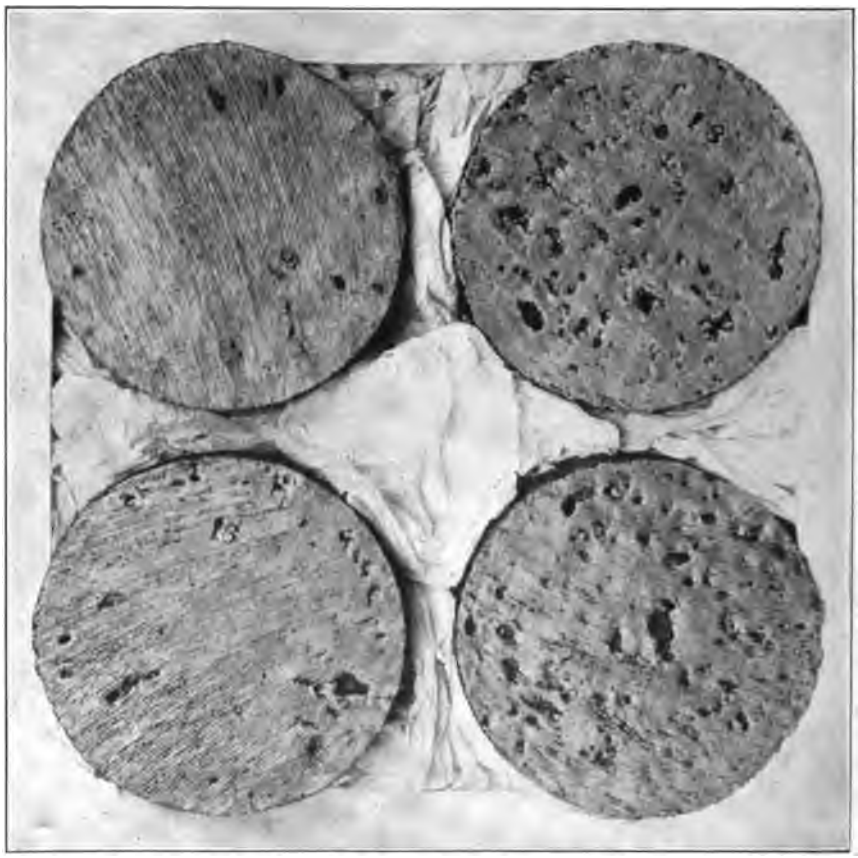


FIG. 14.—INGOTS 13 AND 14 WITH 0.03 PER CENT TI. INGOTS 15 AND 16 WITH 0.10 PER CENT TI.

Transverse section at cropping point. 25 per cent carbon-free ferrotitanium.

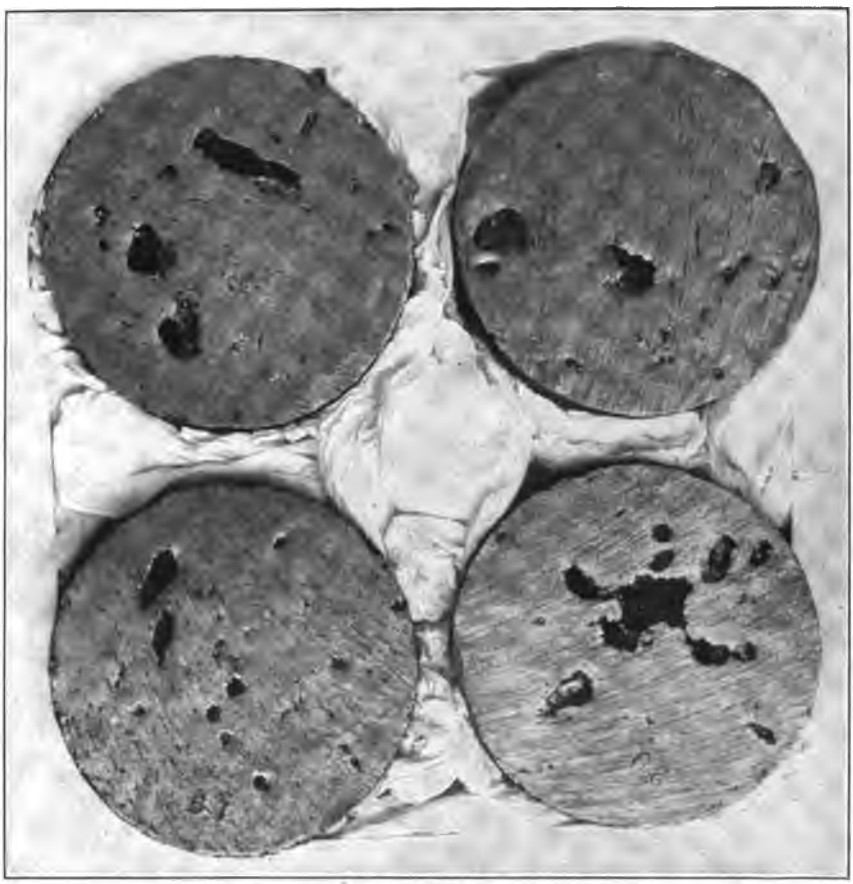


FIG. 15.—INGOTS 17 AND 18 WITH 0.20 PER CENT Si. INGOTS 19 AND 20 WITH 0.30 PER CENT Si.

Transverse section at cropping point.

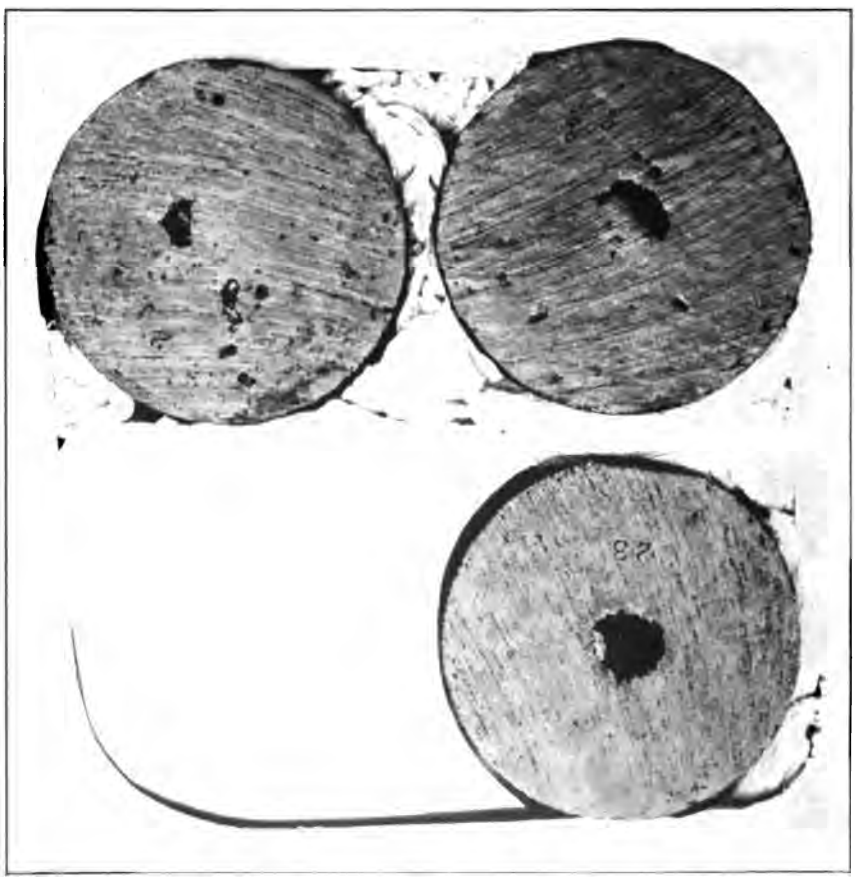


FIG. 16.—INGOTS 21 AND 22 WITH 0.40 PER CENT Si. INGOT 23 WITH 0.50 PER CENT Si.

Transverse section at cropping point.

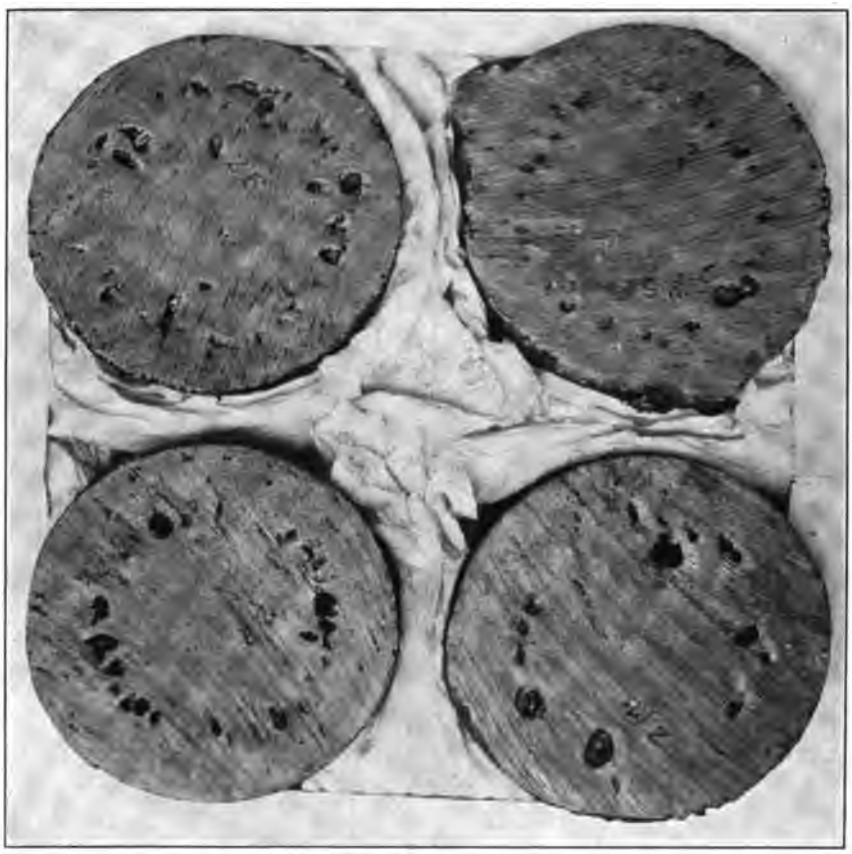


FIG. 17.—INGOTS 25 AND 26 WITH 0.50 PER CENT Mn. INGOTS 27 AND 28 WITH 0.75 PER CENT Mn.

Transverse section at cropping point.

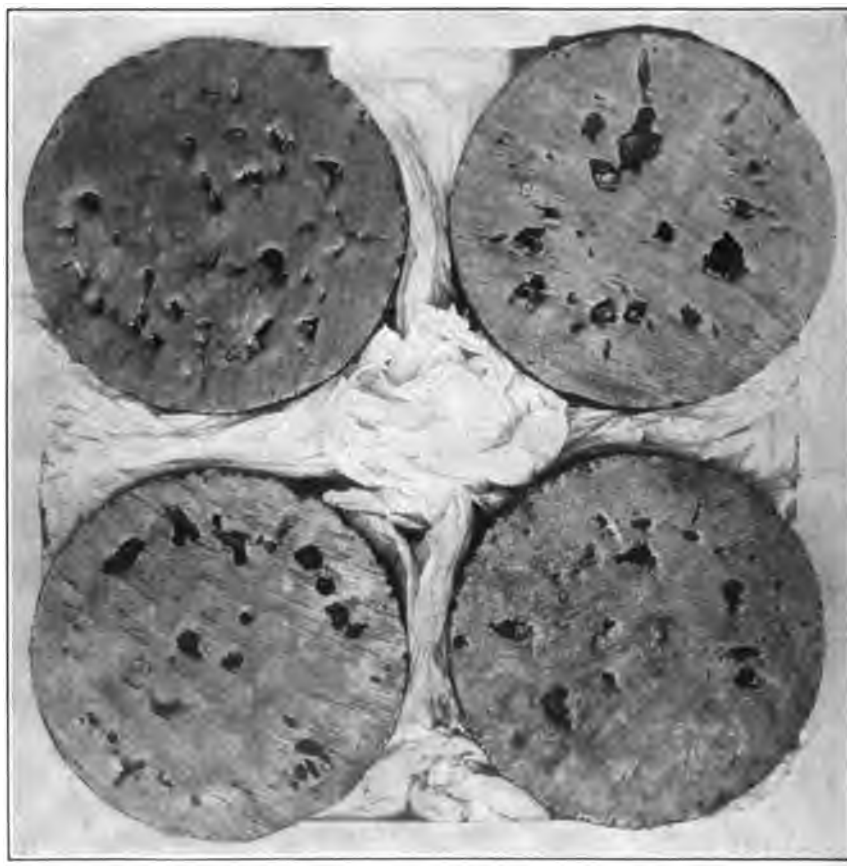


FIG. 18.—INGOTS 29 AND 30 WITH 1.00 PER CENT Mn. INGOTS 31 AND 32 WITH 1.25 PER CENT Mn.

Transverse section at cropping point.

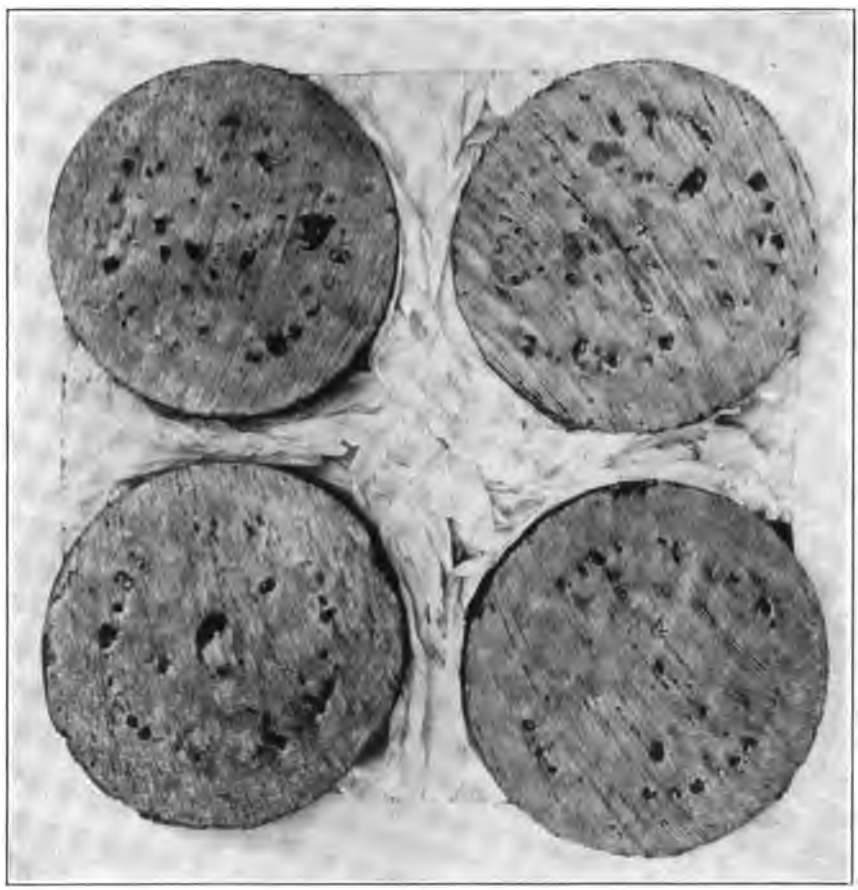


FIG. 19.—INGOTS 33 AND 34 WITH 0.05 PER CENT Al. INGOTS 35 AND 36 WITH 0.10 PER CENT AL.

Transverse section at cropping point. Additions in ladle.

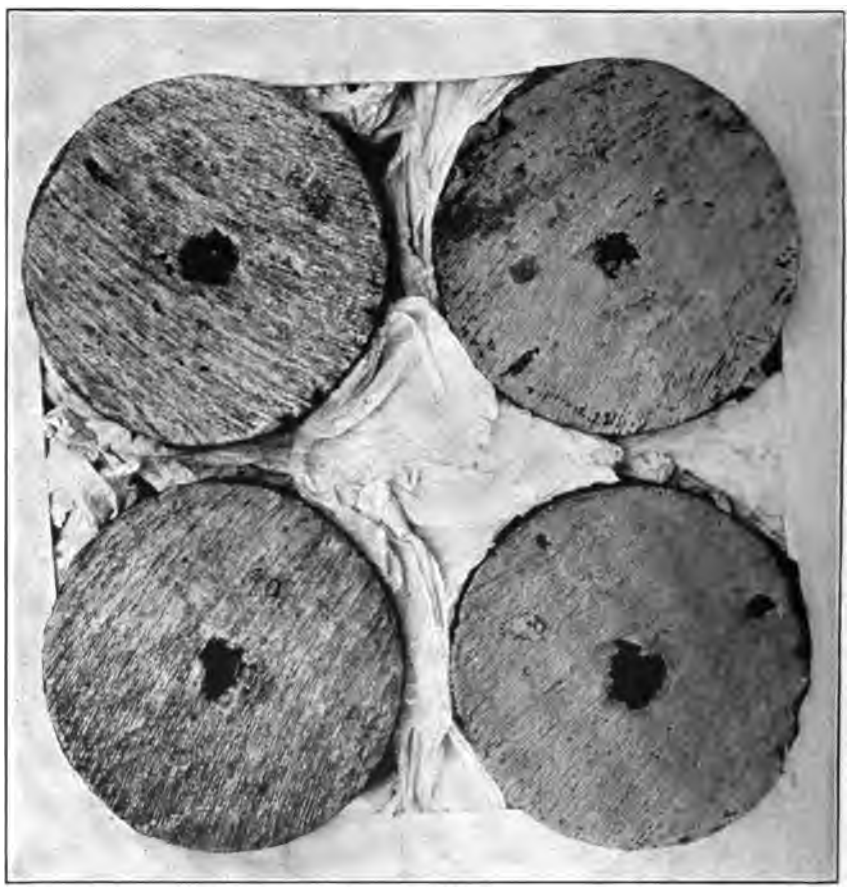


FIG. 20.—INGOTS 37 AND 38 WITH 0.20 PER CENT Al. INGOTS 39 AND 40 WITH 0.30 PER CENT Al.

Transverse section at cropping point. Additions in ladle.

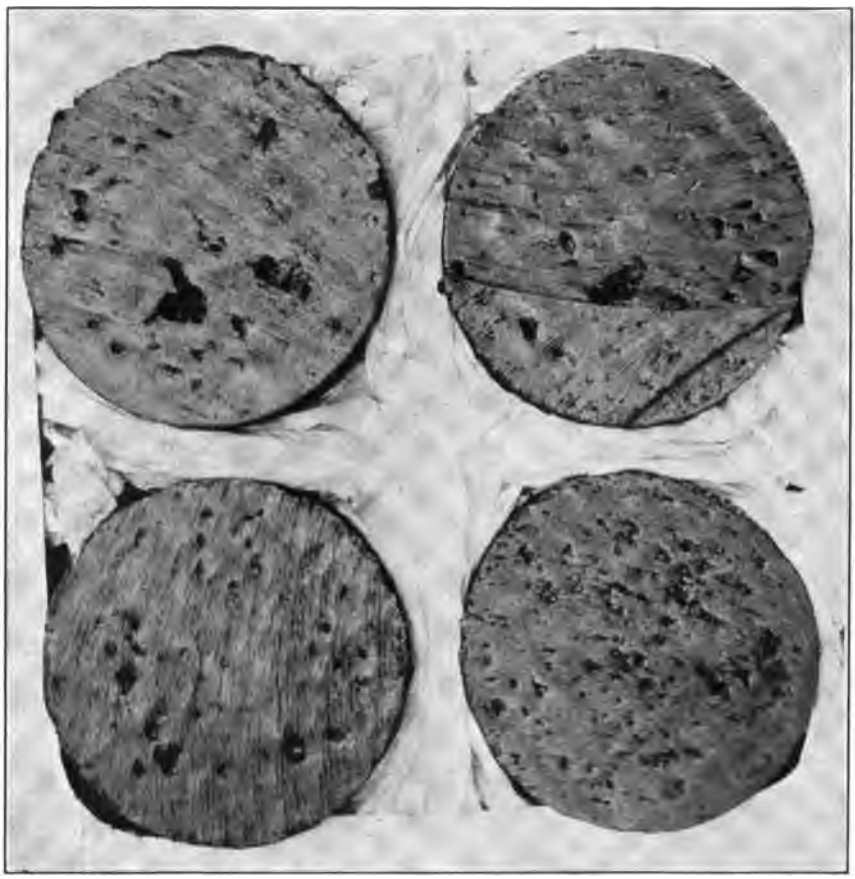


FIG. 21.—INGOTS 41 AND 42 WITH 0.05 PER CENT Al. INGOTS 43 AND 44 WITH 0.10 PER CENT Al.

Transverse section at cropping point. Addition in mold.

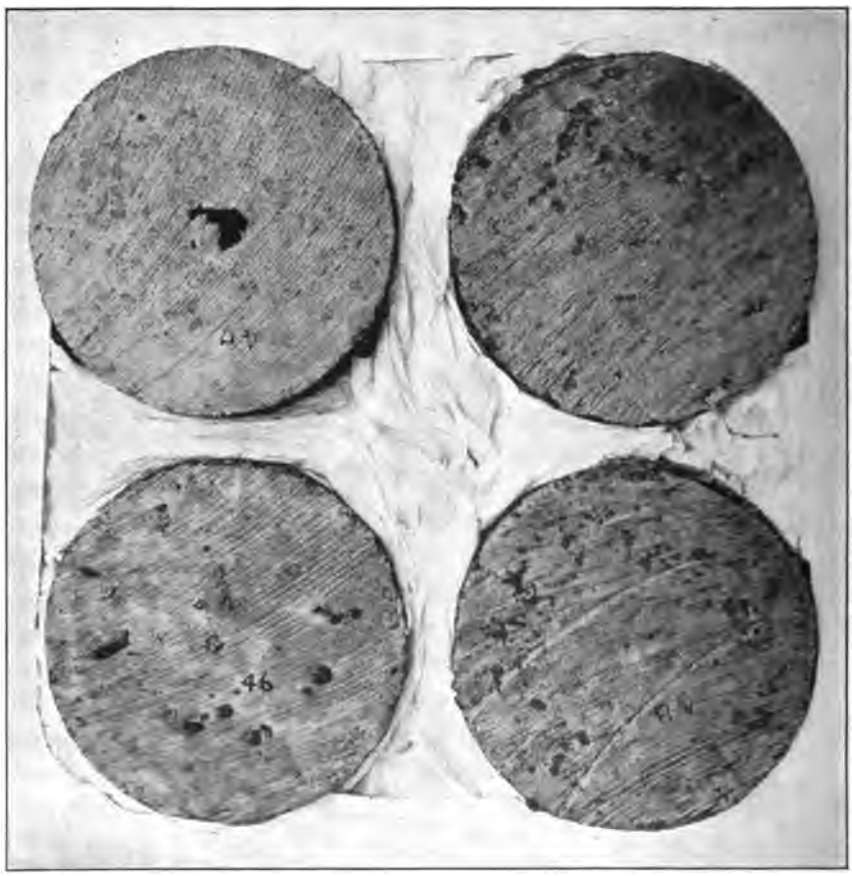


FIG. 22.—INGOTS 45 AND 46 WITH 0.20 PER CENT Al. INGOTS 47 AND 48 WITH 0.30 PER CENT Al.

Transverse section at cropping point. Additions in mold.

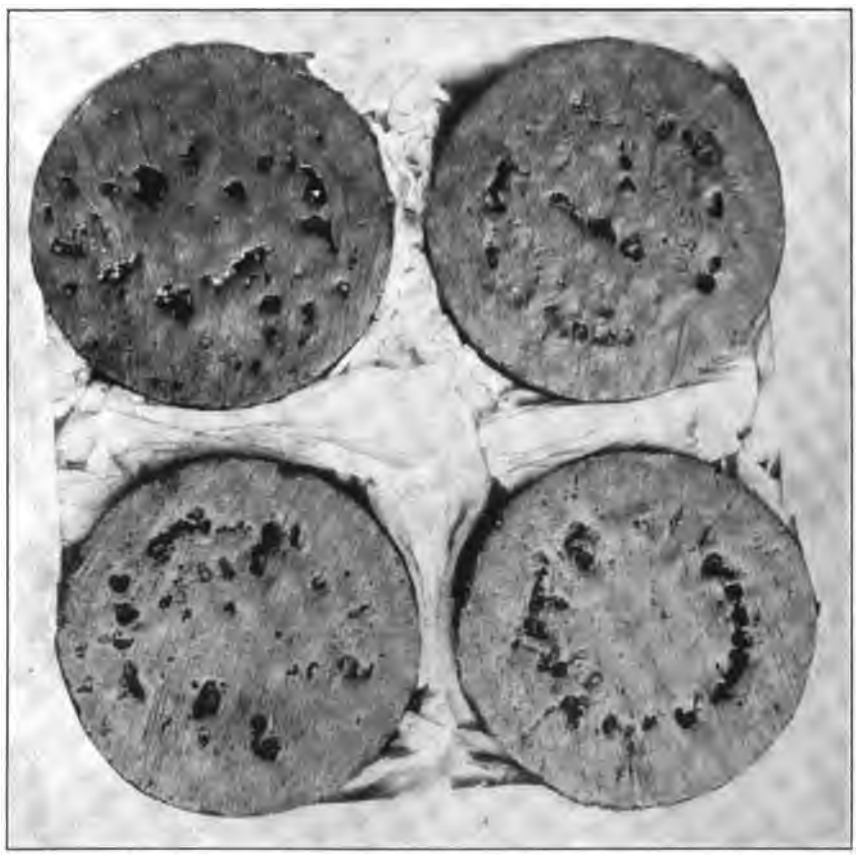


FIG. 23.—INGOTS 49 TO 52 WITH 0.03, 0.045, 0.06, and 0.10 PER CENT Ti, RESPECTIVELY, IN FORM OF 15 PER CENT FERROCARBON TITANIUM.

Transverse section at cropping point.

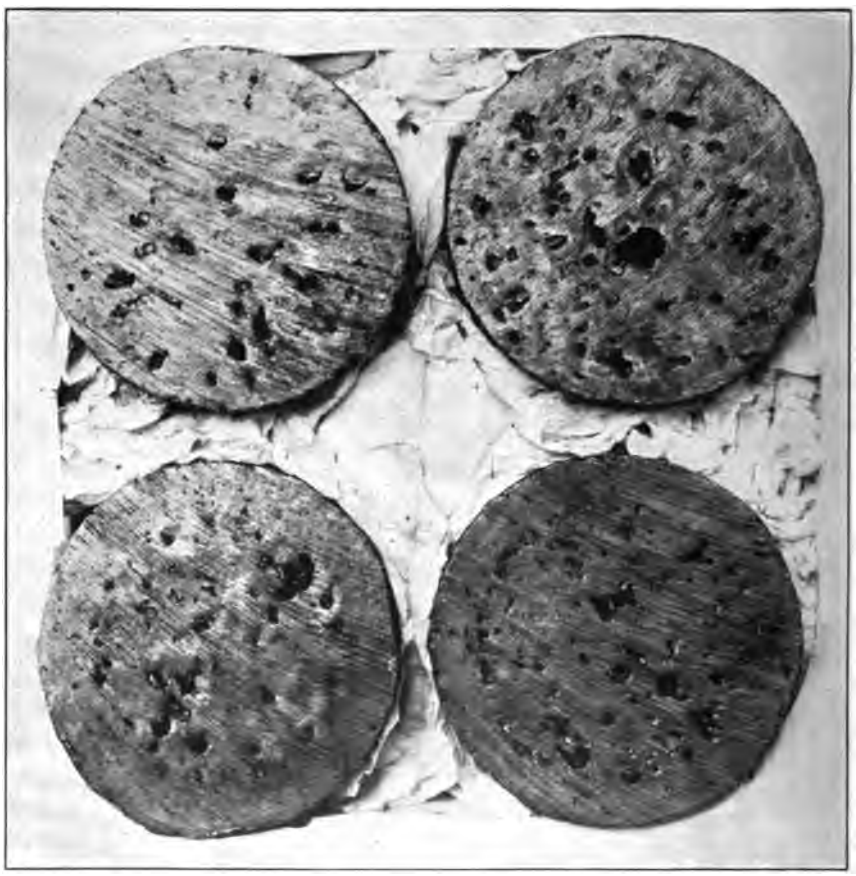


FIG. 24.—INGOTS 53 TO 56 WITH 0.01, 0.02, 0.03, AND 0.10 PER CENT Ti, RESPECTIVELY, IN FORM OF 25 PER CENT CARBON-FREE FERRO-TITANIUM.

Transverse section at cropping point.

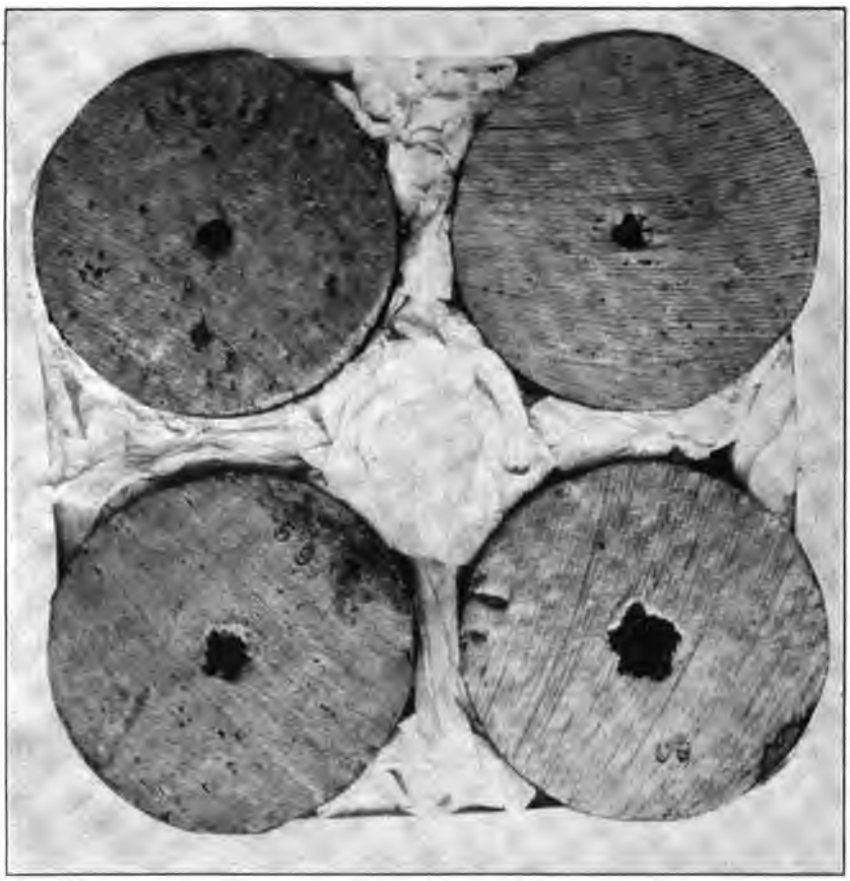


FIG. 25.—INGOTS 57 TO 60 WITH 0.20, 0.30, 0.40, and 0.50 PER CENT Si RESPECTIVELY, IN FORM OF 50 PER CENT FERROSILICON.

Transverse section at cropping point.

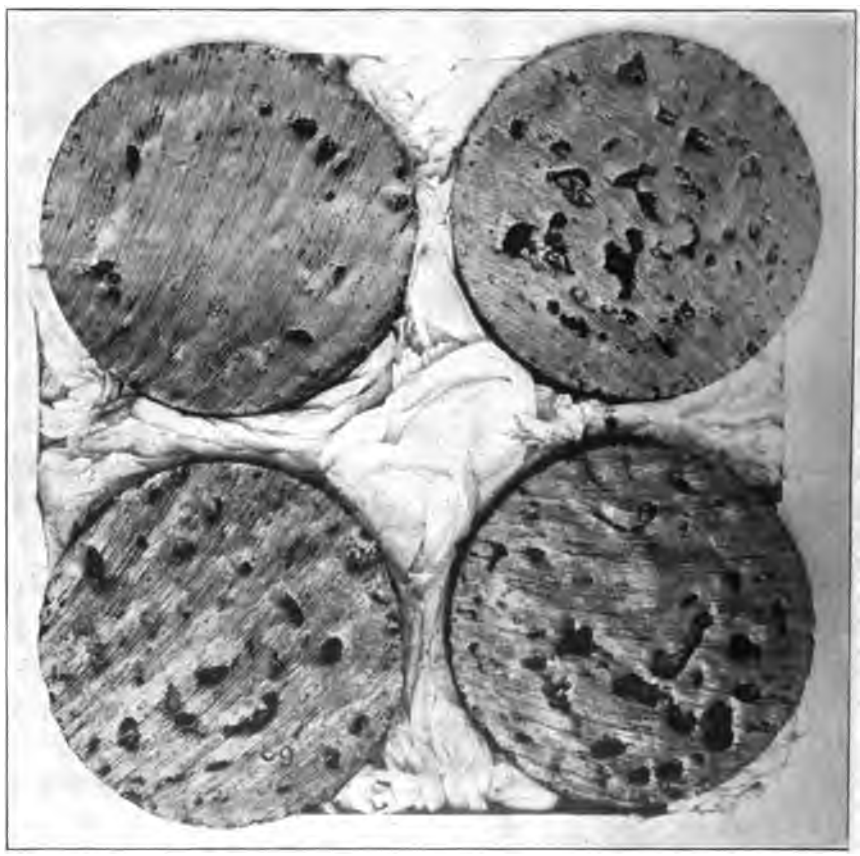


FIG. 26.—INGOTS 61 TO 64 WITH 0.50, 0.75, 1.00 AND 1.25 PER CENT Mn, AS 80 PER CENT FERROMANGANESE.

Transverse section at cropping point.

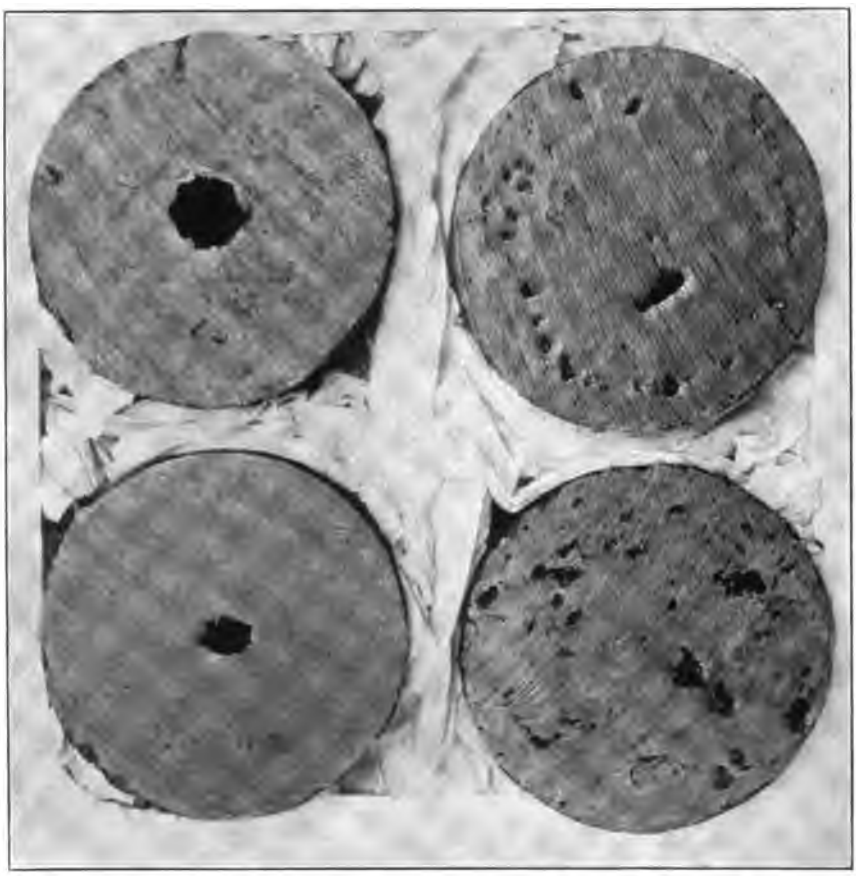


FIG. 27.—INGOTS 65 TO 68 WITH 0.05, 0.10, 0.20, AND 0.30 PER CENT Al, RESPECTIVELY, ADDED IN LADLE.

Transverse section at cropping point.

FIG. 28.—INGOTS 69–72 WITH 0.05, 0.10, 0.20, AND 0.30 PER CENT Al ADDED IN MOLD.

Transverse section at chipping point.

(especially with the carbon-free alloy) and increasing with the manganese content.

The object of experiment 1 was principally to determine the proportion of deoxidizer to be used in experiment 2 and too much value must not be given to the comparison of the various deoxidizers based on this experiment, for it must be remembered that the material used was raw converter metal and not commercial steel and no physical tests (except density) were made. Nevertheless the conclusion is easily drawn, disregarding other additions, and considering only the proportions of deoxidizer used, that aluminum and silicon are notably better agents than the others for increasing the density of blown metal and almost equally effective when the proper proportions are used, with the preference slightly in favor of aluminum (in the ladle). Moreover, the slight porosity of the metal to which these two deoxidizers have been added is due to a slight pipe rather than to blowholes. Of course this conclusion does not take into consideration the effect of the addition upon the physical properties of the metal other than density.

EXPERIMENT 2.

Material used.—One heat of metal from a Tropenas converter was used, the aim being to obtain steel of the following composition:

	Per cent.
C	0.40
Mn	0.50
Si	0.20
P	0.05
S	0.05

Cupola metal of the same analysis as used for the heat of steel was added as a recarburizer (see chemical analysis in Table 8). Enough ferro-manganese and ferro-silicon of the analysis given in Table 8 were used to bring the manganese and silicon content up to the requirements. The various deoxidizers under test were then added in the proportion (determined in experiment 1) which gave the soundest ingots when added to raw converter metal.

Procedure.—Steel was made in the usual way by blowing cupola iron in the Tropenas converter, adding to it the required amount of cupola metal for recarburizing, and teeming the mixture into a preheated 2-ton ladle in which had been weighed the correct proportions of ferro-manganese and ferro-silicon to give the analysis desired. The record of the heat is given in Table 7.

TABLE 7.—*Details of heat.*

Heat No. 4458.	Weight (pounds).	Time.
Metal into converter		2.09. 2.12.
Weight of metals into converter	6,020	
Started to blow		$2^h\ 12^m\ 30^s$.
Blow ended (7 seconds overblown)		$2^h\ 48^m\ 40^s$.
Weight of cupola metal added to converter metal.	425	
Weight empty 2-ton ladle	3,061	
Weight of Fe-Mn added (77.00 per cent Mn).	45	
Weight of Fe-Si added (56 per cent Si).	7	
Converter to 2-ton ladle		3^h.
Weight converter metal added	5,092	
Weight steel+additions	5,569	

In Table 8 are given chemical analyses of the raw materials and of the steel before the deoxidizing additions were made. A comparison of the figures for the calculated analysis with the actual analysis of the steel will show the losses of carbon, manganese, and silicon by combination with the oxides in the oberblown steel. Again, as in experiment 1, 0.17 per cent or one-fourth of the manganese and a small amount of the silicon have been lost.

TABLE 8.—*Chemical analysis of raw material and steel.*

Analysis.	C.	Mn.	Si.	S.	P.
Cupola iron	3.40	0.47	1.65	0.047	0.035
Converter metal	0.082	Trace.	0.016	.....	.....
Converter metal+additions by calculation	0.387	0.68	0.218	0.0537	0.0401
Same, by analysis	0.37	0.51	0.186	0.057	0.037
Ferro-manganese	6.55	77.00	0.908	0.024	0.185
Ferro-silicon	0.16	.....	56.0	.....	.....

The metal in the 2-ton ladle was carried to preheated ladles, each of the capacity of 1,000 pounds. three of these ladles being used. These 1,000-pound ladles had been placed on a scale and weighed, and approximately 1,000 pounds of metal was teemed into each.

The first and second 1,000-pound ladles were used for the fourth and fifth sets of deoxidizers.

The arrangement of molds was approximately as shown in the sketch below, in order to facilitate quick pouring.

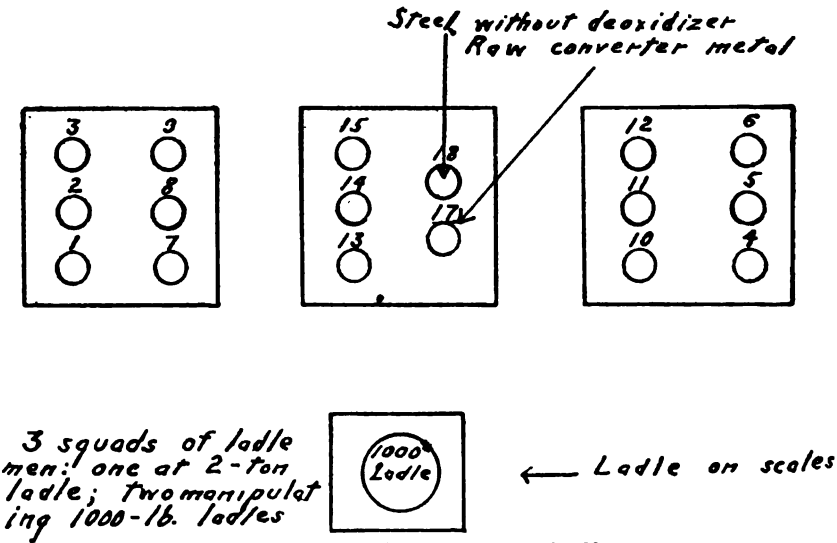


FIG. 29.—Approximate arrangement of molds.

Temperature of pouring.—The process of teeming and pouring was conducted as rapidly as possible to make the temperature of pouring as nearly alike as possible in all cases. An examination of Table 9 will show how quickly this was done. The position of the ingot numbers and the time of pouring as given in the table indicate the order in which the ingots were poured. For instance, ingots 1, 2, and 3 were poured first in the order named, then ingots 7, 8, and 9, then ingots 13, 14, and 15, then ingots 12, 11, and 10, then ingots 6, 5, and 4.

Number of ingots.—Fifteen ingots in all were poured, three with each addition. All the deoxidizing additions were made in the ladle, since it was determined from experiment 1 that aluminum added in the mold did not give as good results as aluminum added in the ladle.

In addition to the above there was cast a small ingot of raw converter metal (ingot 17) and one of converter metal to which the carbon, manganese, and silicon additions had been made, but to which no deoxidizer, considered as such, had been added (ingot 18). Ingots 4 and 10 were small because there was not enough metal left in the 1,000-pound ladle to fill the mold. These two ingots were therefore not tested.

Table 9 gives the time of pouring, the weight and percentage of deoxidizer added, kind of deoxidizer, etc.

TABLE 9.—*Time of pouring and amount of deoxidizer.*

Ingot No.	1, 2, 3	6, 5, 4	7, 8, 9	12, 11, 10	13, 14, 15.
Metal into ladle	3h 5m 50s	3h 16m 55s	3h 7m 30s	3h 14m 48s	3h 8m 55s.
Deoxidizer added	3h 5m 56s	3h 16m 56s	3h 7m 30s	3h 14m 48s	3h 9m 00s.
Finished pouring into ladle.	3h 6m 25s	3h 17m 00s	3h 7m 57s	3h 15m 10s	3h 9m 05s.
Metal poured into first ingot.	3h 00m 20s	3h 19m 45s	3h 10m 25s	3h 17m 14s	3h 11m 35s.
Third ingot finished	3h 10m 56s	3h 21m 20s	3h 11m 34s	3h 18m 31s	3h 13m 00s.
Deoxidizer held in ladle	2m 55s 00s	2m 45s 00s	2m 28s 00s	2m 04s 00s	2m 30s.
Weight of deoxidizer added.	6.98 pounds	6.275 pounds.	4.16 pounds	7.15 pounds	2.02 pounds.
Weight of steel to which added.	1,054 pounds.	1,015 pounds.	1,067 pounds.	1,000 pounds[1].	1,395 pounds.
Deoxidizing element added.	0.095 per ct	0.492 per ct	0.0937 per ct	0.40 per ct	0.144 per ct.
Kind of deoxidizer added	Fe-C-Ti	Fe-Mn	Fe-Ti carbonless.	Fe-Si	Al.
Element in deoxidizer	14.32 per ct	79.65 per ct	24 per ct	56 per ct	99.08 per ct.
Deoxidizer (calculated) per ton of steel.	212 ounces	198 ounces	125 ounces	229 ounces	46 ounces.
Deoxidizing element (calculated) per ton of steel.	30.4 ounces	157.7 ounces.	30 ounces	128 ounces	45.6 ounces.

[1] This weight was estimated as the scales were temporarily unmanageable. There was at least 1,000 pounds in the ladle, however.

Time of holding.—The deoxidized metal was held from two minutes to three minutes in the ladle before pouring into the molds.

Homogeneity of metal.—All ingots were cast from one heat and manganese and silicon additions were added to the entire bulk of steel, so that the steel was as homogeneous as possible. Each 1,000-pound ladle gave enough metal for three ingots and the deoxidizer was added in these ladles, so that the homogeneity of the steel with any given deoxidizing addition was also as homogeneous as possible. The deoxidizer was added to the 1,000-pound ladle while the steel was being poured into it, making the first addition of deoxidizer when the ladle was about half full and completing the additions just before the last portion of steel was poured from the 2-ton ladle. This allowed a thorough mixing of the deoxidizer with the metal.

Size of ingots.—Ingots were made as large as possible, keeping in mind that one heat of metal was to be used for the entire set. The pattern for the mold was made about 25 inches long and 7¼ by 7¾ inches in diameter at the respective ends, the mold being slightly tapered for draft, with the larger end up. The ingots weighed from 179 to 222 pounds each with the exception of ingots 4 and 10, which were discarded. Ingots 17 and 18 were intended to be the same size as the others, but there was not enough metal left.

Splitting and photography of ingots.—All the ingots were sand-blasted and all but ingots 4, 10, 17, and 18 were cropped to 20 per

cent of their length. Ingots 4 and 10 were discarded and 17 and 18 were very small and therefore were not cropped. Each ingot was then split vertically and five of the ingots (Nos. 2, 5, 8, 11, and 14) were etched with a saturated solution of iodine in 95 per cent alcohol to bring out differences in the macroscopic structure due to segregation. All of the ingots were then photographed (see figs. 30 to 35, inclusive).

Piping.—No special precautions were taken to prevent piping by mechanical means. This was intentional, as at the time the plans were made it was thought better not to confuse the effect of mechanical and chemical methods on the formation of pipe, since the prevention of piping as such was not to be studied. It is now believed that it would have been better to reduce or eliminate the pipe by mechanical means, as any effect of the chemical additions (deoxidizers) on the piping would thus have been more clearly shown. As a matter of fact all of the ingots were piped more or less for a considerable distance below the point of cropping. The value of the different deoxidizers as given in terms of the pipe in these cropped ingots would be—

Ferro-carbon titanium.
Ferro-silicon.
Aluminum.
Ferro manganese.
Carbonless ferro-titanium.

The hidden pipe in ingot 8 (carbonless ferro-titanium) is especially noticeable. No evidence of this pipe was visible on the transverse section at the cropping point.

Blowholes are plainly visible in ingots 3 (ferro-carbon-titanium) and 5 and 6 (ferro-manganese). Ingot 5 (ferro-manganese) also has a hidden pipe.

Density.—The half-ingots which were photographed were split in two transversely and the lower end reserved for relative density tests.

Relative density tests were also made on the cropped ingots before splitting vertically, using the same method as in experiment 1. The result of this test is given in Table 10, but no valuable conclusions can be drawn because no attempt was made to distinguish between the porosity due to blowholes and the porosity due to piping.

TABLE 10.

Ingot No.	Weight of ingot.	Relative density.	Average density.	Deoxidizer used.	Order of deoxidizer in respect to density.
1	220.45	7.87			
2	222.41	7.94	7.85	Fe-C-Ti.....	1
3	218.08	7.75			
5	179.13	7.68			
6	195.11	7.84	7.76	Fe-Mn.....	5
7	220.20	7.86			
8	222.58	7.82			
9	216.16	7.78	7.82	{Fe-Ti carbonless.}	2
11	219.23	7.71			
12	219.64	7.83	7.77	Fe-Si.....	4
13	205.32	7.82			
14	211.08	7.75	7.79	Al.....	3
15	218.20	7.81			

NOTE TO TABLE 10.—It will be noted that the average relative densities are very close to each other, especially in the cases of ferro-manganese, ferro-silicon, and aluminum. In any particular group using the same deoxidizer, however, the relative densities vary more than the averages of the different groups. These variations are probably due to differences in casting conditions and it was to eliminate such influences as far as possible that the ingots were cast in triplicate. The same remarks refer to the specific gravity tests on the small specimens given in Table 11.

FIG. 30. INGOTS 1, 2, AND 3. EXPERIMENT 2.

Steel made with 0.10 per cent Ti in form of 15 per cent ferrocarbon titanium. Vertical sections. Ingot 2 etched with iodine.

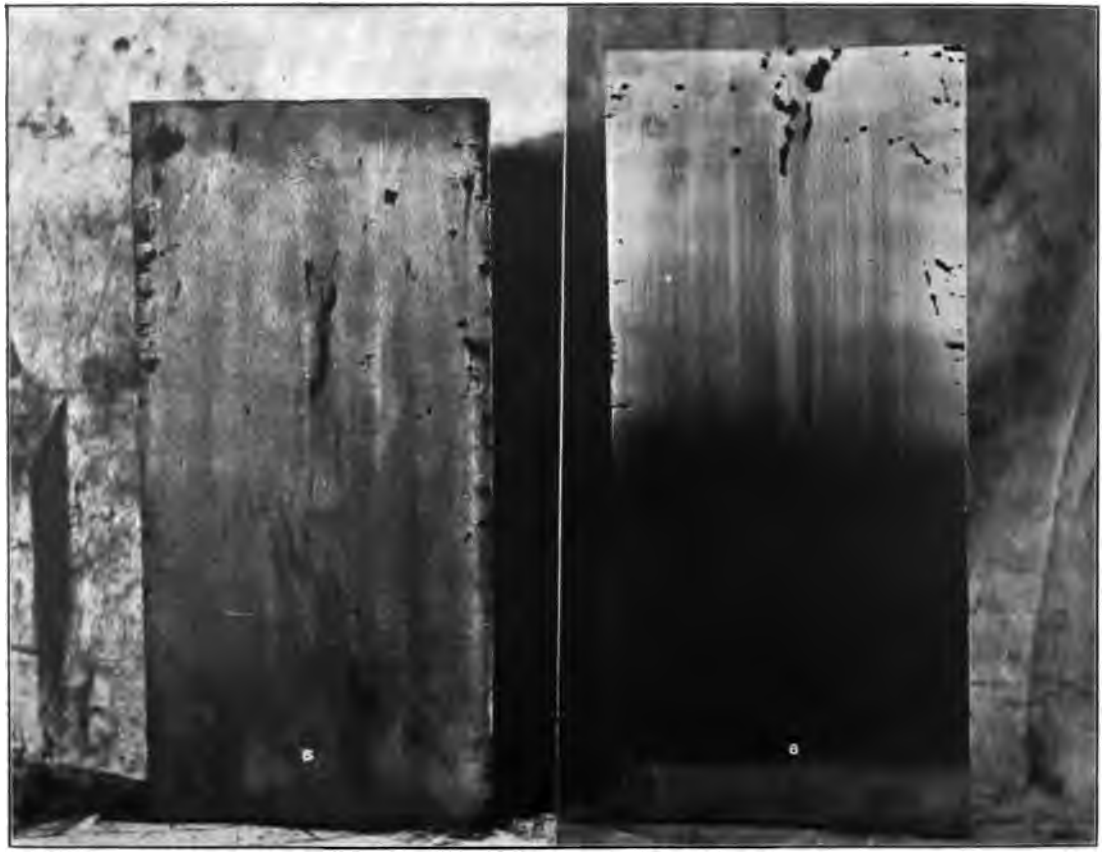


FIG. 31.—INGOTS 5 AND 6. EXPERIMENT 2.

Steel made with about 0.50 per cent Mn in form of 80 per cent ferromanganese. Vertical sections. Ingot 5 etched with Iodine.

FIG. 32.—INGOTS 7, 8, AND 9. EXPERIMENT 2.

Steel made with 0.10 per cent Ti in form of 25 per cent carbon-free ferrotitanium. Vertical sections. No. 8 etched with iodine.

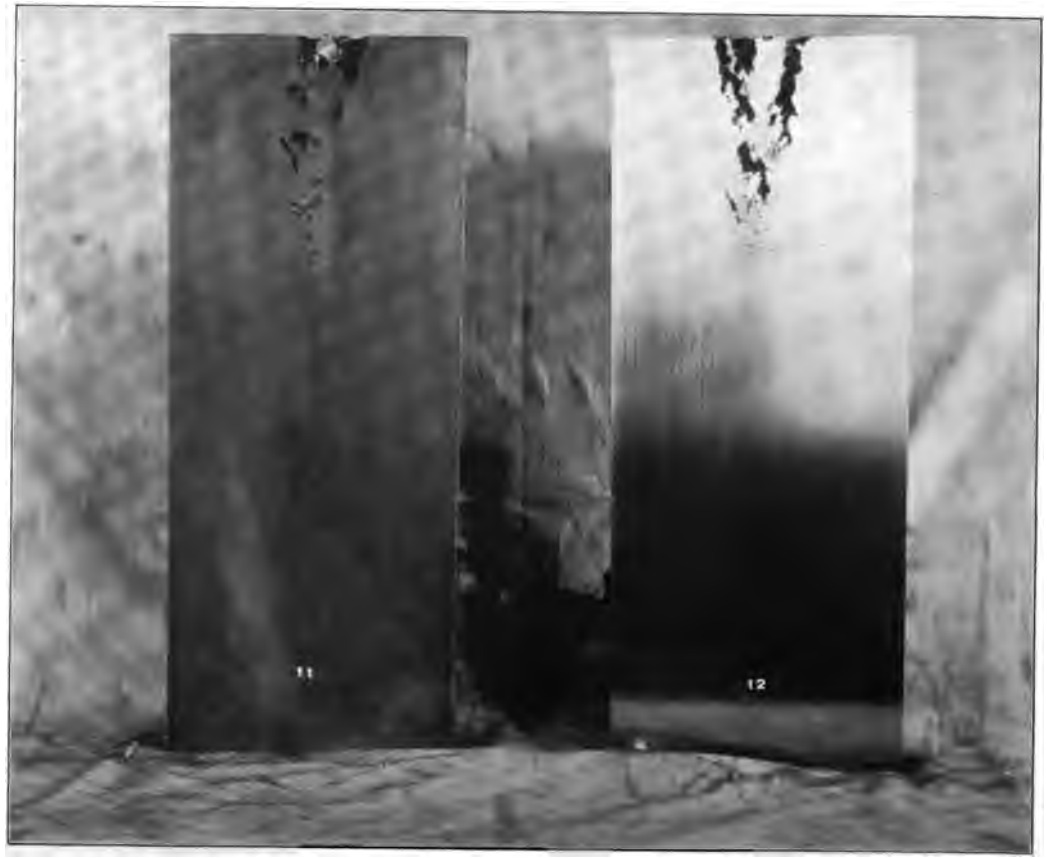


FIG. 33.—INGOTS 11 AND 12. EXPERIMENT 2.
Steel made with about 0.40 per cent Si in form of 50 per cent ferrosilicon. Ingot 11 etched with Iodine.

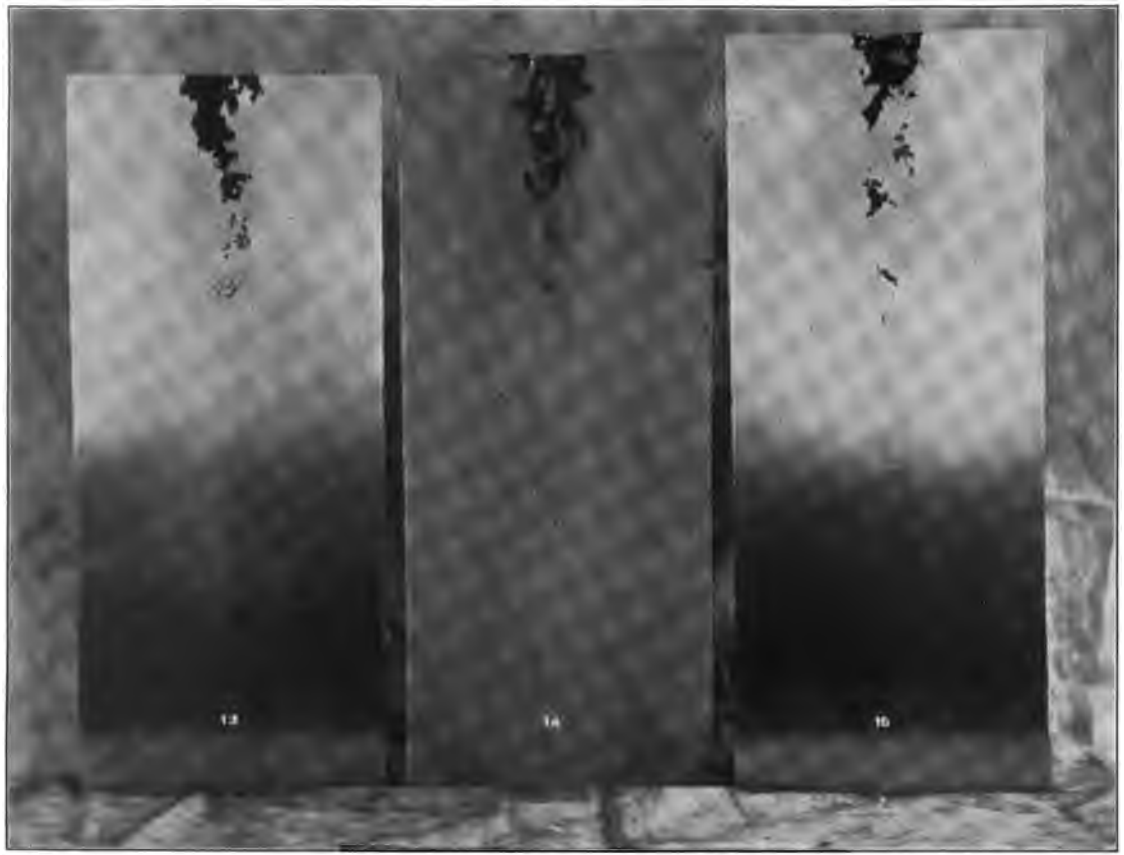


FIG. 34.—INGOTS 13, 14, AND 15. EXPERIMENT 2.

Steel made with about 0.15 per cent Al in form of 99 per cent granulated aluminum. Vertical section. Ingot 14 etched with iodine.

FIG. 35.—INGOT 17, RAW CONVERTER METAL; INGOT 18, SAME WITH FERROMANGANESE AND FERROSILICON ADDED BUT NO DEOXIDIZER.

Figure 36 (a and b) shows the manner in which the cropped ingots were cut up for the various tests. Pieces located at GG in half-ingot A have been reserved for gas-extraction tests. A 2-inch slice was cut out at the locations Ct and Cc and a bar about 2 inches square was cut from this slice, the portion Ct being machined for tensile test bars (see Tables 12–15), the portion Cc for Charpy test bars (see Tables 16 and 17) and pieces shown at S for specific gravity tests referred to in Table 11. The section on O-O shows the location on the lower half of this half-ingot of the samples for oxide determinations.

The lower half of this half-ingot marked F was forged as shown in figure 36b and tensile and Charpy tests were taken as shown in that sketch.

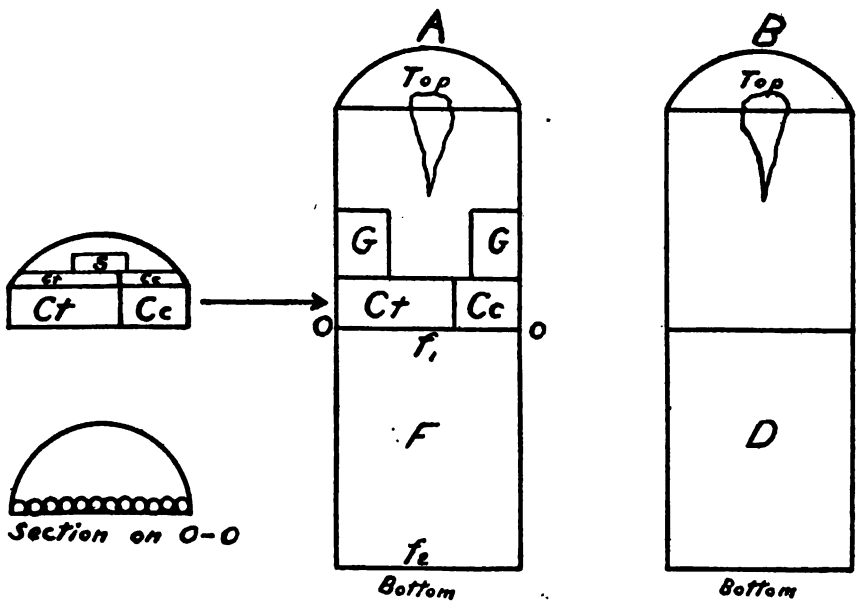


Fig 36 a

The lower half of the half-ingot B (marked D) has been reserved for density tests.

The half-ingot B was also used for determining segregation by chemical analysis, etching tests, and photography.

Specific gravity tests were made on small specimens weighing about 50 grams and taken from the point indicated in the sketch above (fig. 36). These are not considered of much value, as one large blow-hole in any specimen might vitiate the results, as is evidently the case in ingot 6. The results are given for what they are worth, however, and it is interesting to note the general agreement between the results of this test and the results of the relative density test given in Table 10. It is believed, however, that the relative density tests on the quarter-ingots reserved as indicated above will be more valuable

than those given in either Table 10 or 11, as the samples are much more representative, bearing in mind that the purpose of these tests is to show the relative freedom from blowholes and nonmetallic inclusions, both of which would affect the density.

TABLE 11.—*Specific gravity tests from S, Fig. 36a.*

Ingot No.	Specific gravity.	Average specific gravity.	Deoxidizer used.	Order of deoxidizers as regards specific gravity.
1	7.765			
2	7.773	7.769	Fe-C-Ti	2 or 3.
3	7.768			
5	7.773			
6	7.732	7.753	Fe-Mn	4.
7	7.775			
8	7.775	7.773	Fe-Ti carbonless	1.
9	7.770			
11	7.746			
12	7.745	7.746	Fe-Si	5.
13	7.764			
14	7.776	7.769	Al	3 or 2.
15	7.766			

Forging.—One-quarter of each ingot (see sketch, fig. 36b) was forged down to 2 inches round under a steam hammer after heating to the usual forging temperature.

Annealing.—Pieces were cut from the upper half of each half-ingots A (see sketch, fig. 36a), the pieces being about 2 inches square and about 7 inches long. These were heated in a semi-muffle type oil-fired shop furnace to 850° C., held for one hour, and cooled in air. All 13 pieces were removed from the furnace within two minutes, so that the rate of cooling of all of them was practically the same. These pieces, together with pieces of about the same size from the forged metal, were then heated to 850° C., held 30 minutes, and cooled in air. They were then reheated to 650° C. for about 30 minutes and cooled in air. The bars from the forged metal were chosen as follows: Three inches were discarded from the end of the bar representing the upper end of the lower half-ingot (see sketch, fig. 36). A piece long enough for one tensile and four Charpy test pieces was then cut off and annealed as described above.

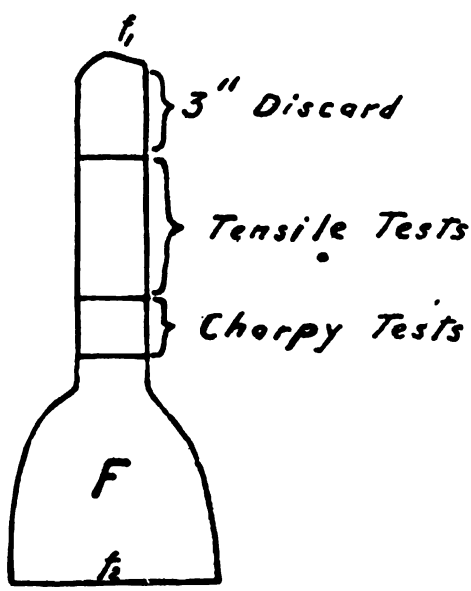


Fig. 36b.

Physical tests.—Tensile test pieces and Charpy impact test pieces were cut from the annealed material and subjected to tensile and

Charpy impact tests, respectively, with the results given in Tables 12 to 17, inclusive.

TABLE 12.—*Tensile tests of annealed cast specimens.*

[Diameter of specimens—0.505 in. Area—.20 sq. in.]

Ingot No.	Yield point (pounds per square inch).	Tensile strength (pounds per square inch).	Elongation in 2 inches (per cent).	Contraction of area (per cent).	Appearance of fracture.
1	46,000	74,000	11.0	24.0	Amorphous, with patches of granular.
2	44,500	69,500	9.0	13.3	Do.
3	47,500	67,500	8.5	16.9	Amorphous, with dark-colored spot at circumference.
5	46,000	75,000	11.0	20.5	Do.
6	45,500	65,500	7.5	20.5	Amorphous, with patches of dark-colored metal near circumference.
7	49,000	65,500	5.5	9.5	Amorphous, with granular spot at circumference.
8	49,500	68,000	5.5	.....	Amorphous; fractured outside gage marks.
9	38,000	49,000	6.0	13.3	Amorphous, with dark-colored patch at circumference.
11	46,000	70,500	9.5	13.3	Amorphous, with granular and light-colored spots.
12	49,000	70,500	9.0	16.9	Amorphous, with granular spots near circumference.
13	41,500	55,000	5.0	5.7	Do.
14	37,500	48,500	4.5	9.5	Amorphous, with dark-colored patches at circumference.
15	39,000	65,500	9.5	13.3	Amorphous.

TABLE 13.—*Average physical tests, annealed cast metal.*

[Calculated from Table 12.]

Ingot No.	Deoxidizer used.	Average yield point.	Average tensile strength (pounds per square inch).	Average elongation in 2 inches (per cent).	Average contraction of area (per cent).	Order of deoxidisers as regards physical properties.	
						Tensile strength.	Elongation.
1, 2, 3	Fe-C-Ti.....	46,000	70,300	9.5	18.1	2	1
5, 6	Fe-Mn.....	45,800	70,000	9.2	20.5	3	3
7, 8	Fe-Ti carbonless.....	45,500	60,800	5.7	11.4	4	5
11, 12	Fe-Si.....	47,500	70,500	9.3	15.1	1	2
13, 14, 15	Al.....	39,300	56,300	6.3	9.3	5	4

TABLE 14.—*Tensile tests of annealed forged steel specimens.*

[Diameter of specimens—0.505 in. Area—.20 sq. in.]

Ingot No.	Yield point (pounds per square inch).	Tensile strength (pounds per square inch).	Elongation in 2 inches (per cent).	Contraction of area (per cent).	Appearance of fracture.
1 F	47,500	82,500	27.5	49.1	Silky.
2 F	52,000	82,000	29.0	51.9	Do.
3 F	51,000	81,500	28.5	51.9	Silky; opened seams in stem.
5 F	48,000	83,500	25.5	46.2	Do.
6 F	49,000	79,000	30.5	54.6	Do.
7 F	46,000	77,000	31.0	57.2	Silky; opened seam in stem.
8 F	48,500	78,000	31.5	57.2	Silky; opened seams in stem.
9 F	50,500	84,000	26.5	46.2	Silky; open seam at center.
11 F	52,500	82,500	29.0	54.6	Silky.
12 F	53,500	84,500	28.5	51.9	Silky; open seam in stem.
13 F	47,000	78,500	29.5	57.2	Do.
14 F	48,500	78,000	31.0	54.6	Do.
15 F	44,500	79,500	29.5	51.9	Do.

TABLE 15.—*Average physical tests, annealed forged metal.*

[Calculated from Table 14.]

Ingot No.	Deoxidizer used.	Average yield point.	Average tensile strength (pounds per square inch).	Average elongation in 2 inches (per cent).	Average contraction of area (per cent).	Order of deodorizers as regards physical properties.	
						Tensile strength.	Elongation.
1 F 2 F 3 F	Fe-C-Ti	50,200	82,200	28.3	51.0	2	4
5 F 6 F 7 F	Fe-Mn	48,500	81,300	28.0	50.4	3	5
8 F 9 F	Fe-Ti carbonless	48,300	79,700	29.7	53.5	4	2
11 F 12 F 13 F	Fe-Si	53,000	83,500	28.8	53.3	1	3
14 F 15 F	Al	46,700	78,700	30.0	54.6	5	1

TABLE 16.—*Charpy tests on annealed cast steel.*

[Four pieces from each ingot were tested.]

Deoxidizer.	Ingot number.	Annealed cast steel (foot-pounds per square inch).				Relative order of deoxidizers.
		Maximum.	Minimum.	Average.	General average.	
Fe-C-Ti	1	147.5	104.0	119.3	119.0	2
	2	124.0	120.0	121.0		
	3	134.5	105.5	116.7		
	4					
Fe-Mn	5	120.0	97.7	109.0	116.8	3
	6	140.4	105.5	124.6		
	7	113.6	92.0	100.6		
Carbonless Fe-Ti	8	120.2	77.8	91.8	94.6	5
	9	120.5	70.2	91.5		
	10					
Fe-Si	11	127.0	98.5	108.9	131.5	1
	12	167.5	135.2	154.2		
	13	121.0	79.0	103.3		
Aluminum	14	149.6	105.6	125.2	114.9	4
	15	133.0	91.9	116.3		

TABLE 17.—*Charpy tests on annealed forged steel.*

[Four pieces from each ingot were tested.]

Deoxidizer.	Ingot number.	Annealed forged steel (foot-pounds per square inch).				Relative order of deoxidizers.
		Maximum.	Minimum.	Average.	General average.	
Fe-C-Ti	1	196.6	164.0	184.3	188.0	5
	2	188.2	157.0	178.2		
	3	246.8	165.6	201.4		
	4					
Fe-Mn	5	229.0	212.0	221.0	221.5	3
	6	231.2	204 0	222.0		
	7	315.2	237.2	266.3		
Carbonless Fe-Ti	8	318.0	246.0	279.6	287.3	2
	9	376.0	288.0	316.0		
	10					
Fe-Si	11	220.8	189.8	200.3	208.0	4
	12	248.0	188.2	215.8		
	13	384.0	332.8	359.1		
Aluminum	14	368.0	302.0	336.7	340.0	1
	15	354.2	279.4	324.2		

It will be noted that in the tensile and Charpy tests the differences between the averages of the various groups of ingots are often less than the differences between many of the physical properties in the same group, this term being understood to include the two or three ingots cast with the same deoxidizer.

Segregation.—Carbon determinations were made in duplicate by the direct combustion process from five of the ingots (Nos. 1, 6, 9, 12, 15) and the results are shown in figs. 37 to 41 inclusive.

In ingot No. 1, made with ferro-carbon-titanium, the tests have not brought out any segregation of carbon; in fact there may be said to be a slight negative segregation since the average carbon at the bottom of the pipe (drill hole No. 6, fig. 37) is 0.366 per cent, while the average at drill hole No. 4 at the outside of the ingot is 0.399 per cent, and that at drill hole No. 15 is 0.385 per cent; and the average carbon from the five drill holes on the axis of the ingot is 0.368 per cent, while the average carbon at the five drill holes on the outside of the ingot is 0.391 per cent. The same thing is true of ingot No. 6, made with ferro-manganese addition, in which the carbon at the bottom of the pipe is 0.372 per cent (drill hole No. 6, fig. 38), while at the corresponding point on the outside of the ingot (drill hole No. 4) the carbon is 0.403 per cent. The average carbon from the five holes representing the axis of the ingot is 0.382 per cent, while the average carbon at the outside of the ingot is 0.397 per cent. The same remarks apply also in general to ingot No. 9, made with carbon-free ferro-titanium. The carbon at the bottom of the pipe is 0.366 per cent (drill hole No. 6, fig. 39), while the carbon at the corresponding point on the outside (drill hole No. 4) is 0.394 per cent, and the average carbon in the axis is 0.371 per cent, while the average carbon on the outside is 0.377 per cent. The difference between the inside and the outside in this ingot however is not so well marked as in the others. But at drill hole No. 3, situated near the pipe, positive segregation is shown, the carbon being 0.442 per cent. In ingot No. 12, made with ferro-silicon, there is a slight segregation of carbon at the bottom of the pipe, the average carbon at drill hole No. 6, fig. 40, being 0.609 per cent, while the carbon at the corresponding point on the outside (drill hole No. 4) is 0.375 per cent. In this ingot the average axial carbon is 0.407 per cent, while the average carbon at the outside is 0.361 per cent. In ingot No. 15, made with aluminum, there is also a distinct positive segregation, the carbon at the lower end of the pipe (drill hole No. 6, fig. 41) being 0.528 per cent, while the carbon at the corresponding point on the outside of the ingot (drill hole No. 4) is 0.396 per cent. The average axial carbon in this ingot is 0.408 per cent, while the carbon at the outside of the ingot averages 0.382 per cent.

If we consider each ingot to be made up of three concentric cylinders, the inner one solid with a diameter of 2 inches, the second one hollow with inside diameter of 2 inches and outside diameter of 4 inches, and the third hollow with inside diameter of 4 inches and outside diameter of 7 inches, it is easy to calculate the approximate carbon content of each ingot by assigning to the central cylinder of metal a carbon content equal to the mean of the axial carbon determinations, to the second cylinder a carbon content equal to the mean of the analyses between the axis and the outside, and to the outside cylinder the mean of the analyses taken at the outside.

The following table gives the result of such a calculation and shows the influence of the various deoxidizers on segregation and their relative merits based on this criterion:

TABLE 18.—*Relative value of deoxidizers as regards prevention of segregation.*

Kind of deoxidizer.	Order of deoxidizer.	Percentage segregation.
		Per cent.
Fe-Mn	1	+ 2
Fe-C-Ti	2	− 5
Fe-Ti (carbonless)	3	+18
Al	4	+44
Fe-Si	5	+64

Extraction of gases.—It was hoped that the extraction of gases, at a high temperature in vacuo, from samples of the various ingots would throw some light on the action of the so-called deoxidizers, especially since Thomas Baker in his paper entitled "Gases occluded in steel,"[1] showed that in comparing cast crucible steel of about 0.80 to 0.90 per cent carbon, with and without the addition of "a small amount of aluminum," the former gave off twice the volume of total gases obtained from the latter during 110 hours heating at 1,000° C. His heatings were made for 10 days at about 11 hours a day. A brief summary of Baker's results is given below in Table 19.

TABLE 19.—*Summary of Baker's results.*

Kind of steel.	Total gases per gram of steel.	CO_2.	H_2.	CO.	CH_4.	N_2.
	cc.	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*
1. Sound steel 0.90 per cent C	1.33	1.68	52.03	45.53	0.72	0.04
2. Unsound steel 0.81 per cent C	.665	.87	54.62	42.41	1.73	.37

Weight of steel sample No. 1, 69.31 grams; sample No. 2, 63.261 grams.

If proper apparatus could have been had for collecting the gases given off from the molten steel, a better basis of comparison between deoxidizers would doubtless have been established, but this was impracticable. It was decided in the present work to extract the gases at 1,000° C. for 30 hours since it was found by experiment that the rate of evolution of gas after that time was very low.

The apparatus used in this work follows closely that employed by Baker.

The heating unit consisted of an alundum tube wound with No. 18 Nichrome wire, the entire winding having a resistance of 19 ohms. The alundum tube was 12 inches in length, the internal diameter being $1\frac{1}{4}$ inches with walls $\frac{3}{16}$ inch thick. A fused silica tube, glazed both inside and outside, was placed concentrically in the alundum tube, the length of the silica tube being 24 inches, with an internal diameter of $\frac{7}{8}$ inch. In the work by Baker a porcelain tube was used, but it is thought that fused silica has several advantages over porcelain for

[1] Iron and Steel Institute, Carnegie Scholarship Memoirs, Vol. I, 1909, p. 219.

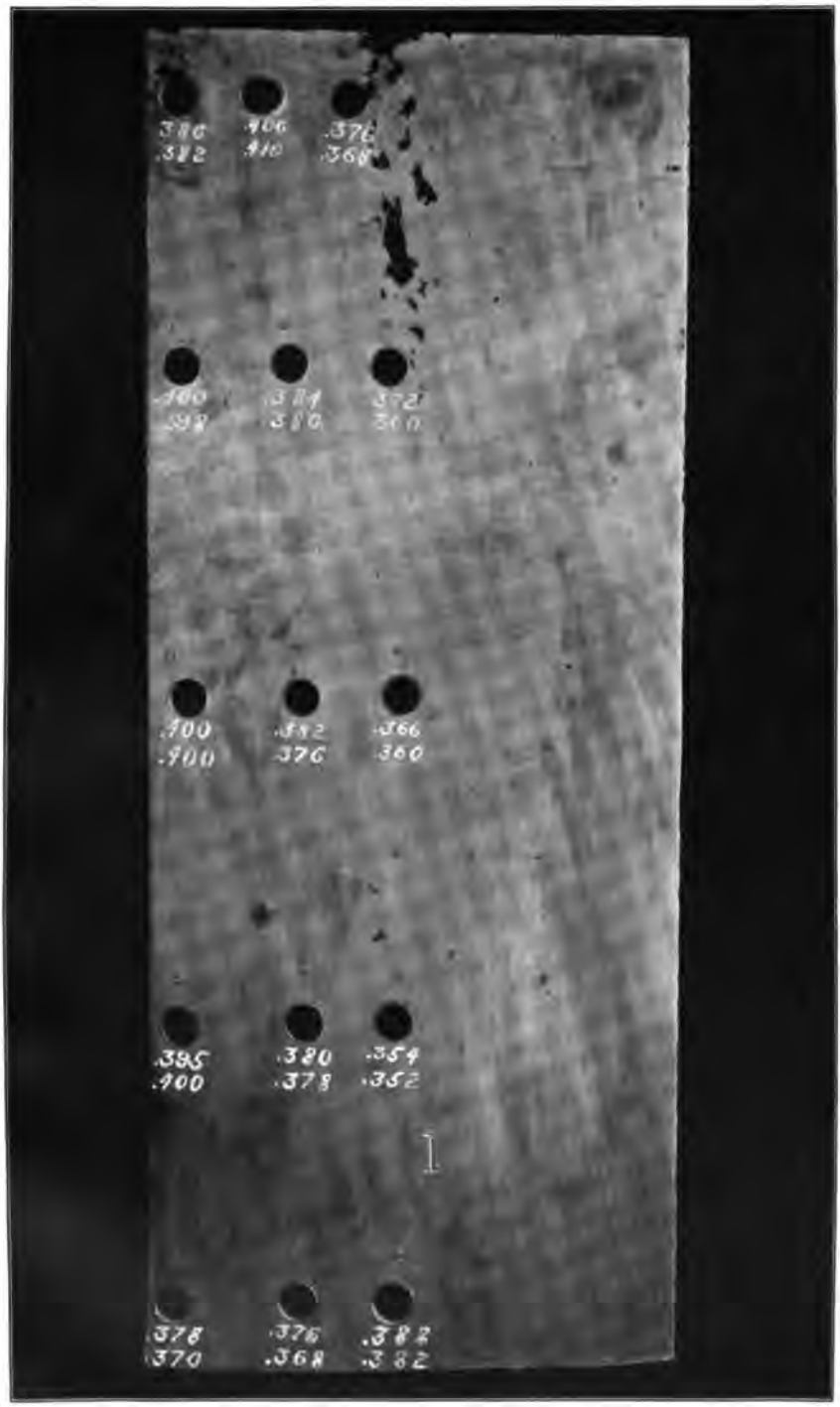


FIG. 37.—INGOT 1. EXPERIMENT 2.

Steel made with about 0.10 per cent Ti in form of 15 per cent ferrocarbon titanium with carbon determinations showing lack of segregation. Vertical section.

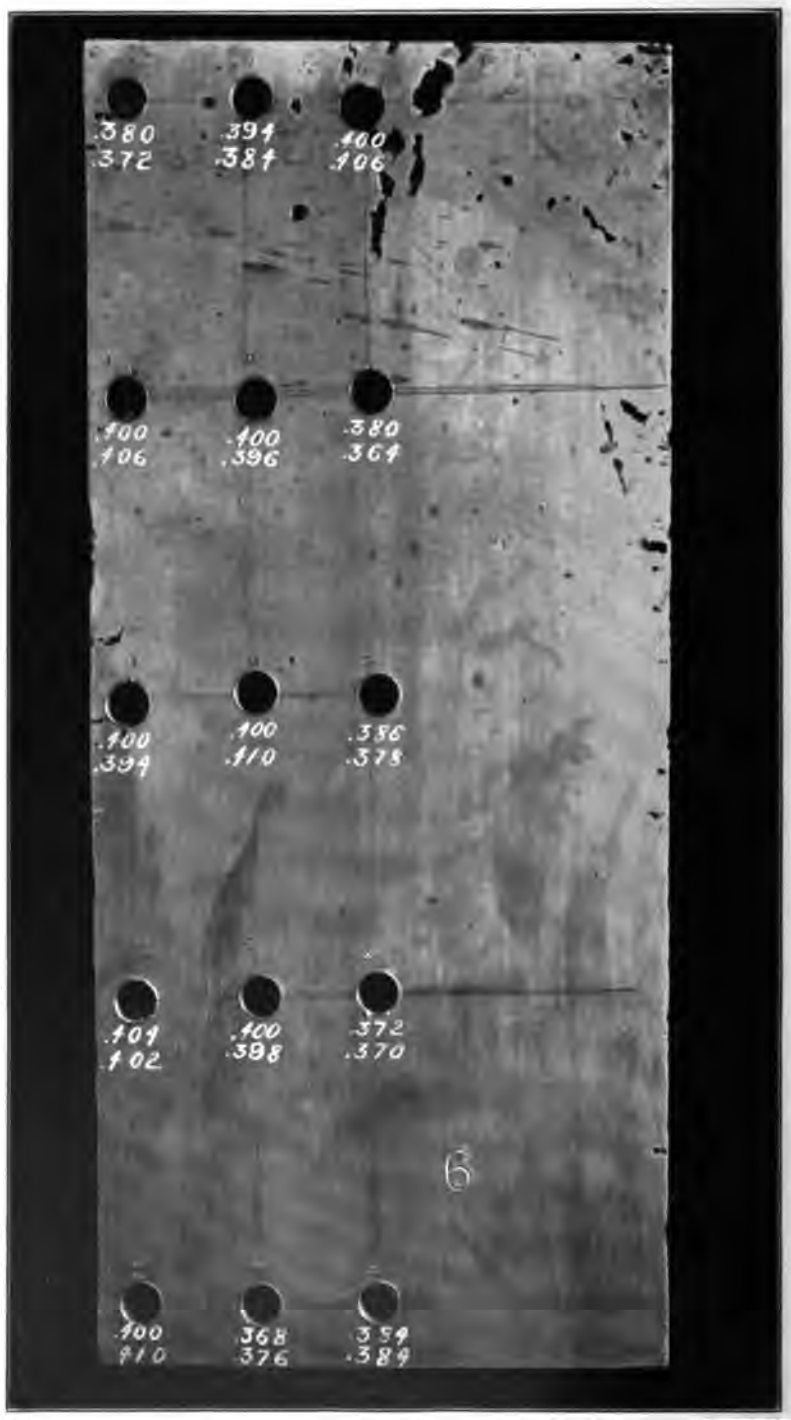


FIG. 38.—INGOT 6. EXPERIMENT 2.

Steel made with about 0.50 per cent. Mn in form of 80 per cent ferromanganese. Vertical section with carbon determinations showing lack of segregation.

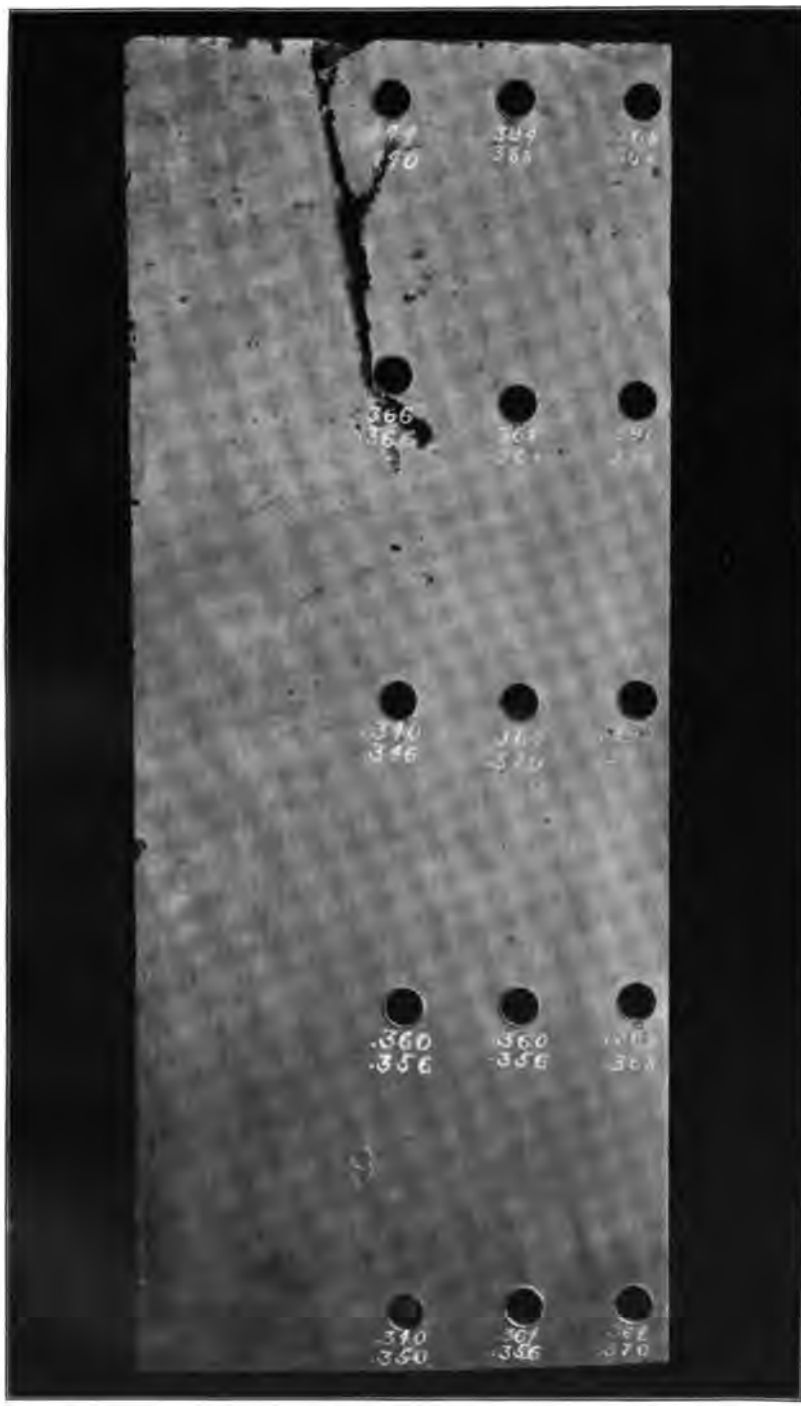


FIG. 39.—INGOT 9. EXPERIMENT 2.

Steel made with about 0.10 per cent Ti in form of 25 per cent carbon-free ferrotitanium. Vertical section with carbon determinations showing slight segregation near pipe.

FIG. 40.—INGOT 12. EXPERIMENT 2.

Steel made with about 0.40 per cent Si in the form of 50 per cent ferrosilicon. Vertical section with carbon determinations showing approximately 60 per cent segregation of carbon at drill hole No. 6 located at the bottom of the pipe and about 30 per cent from the top of the original ingot.

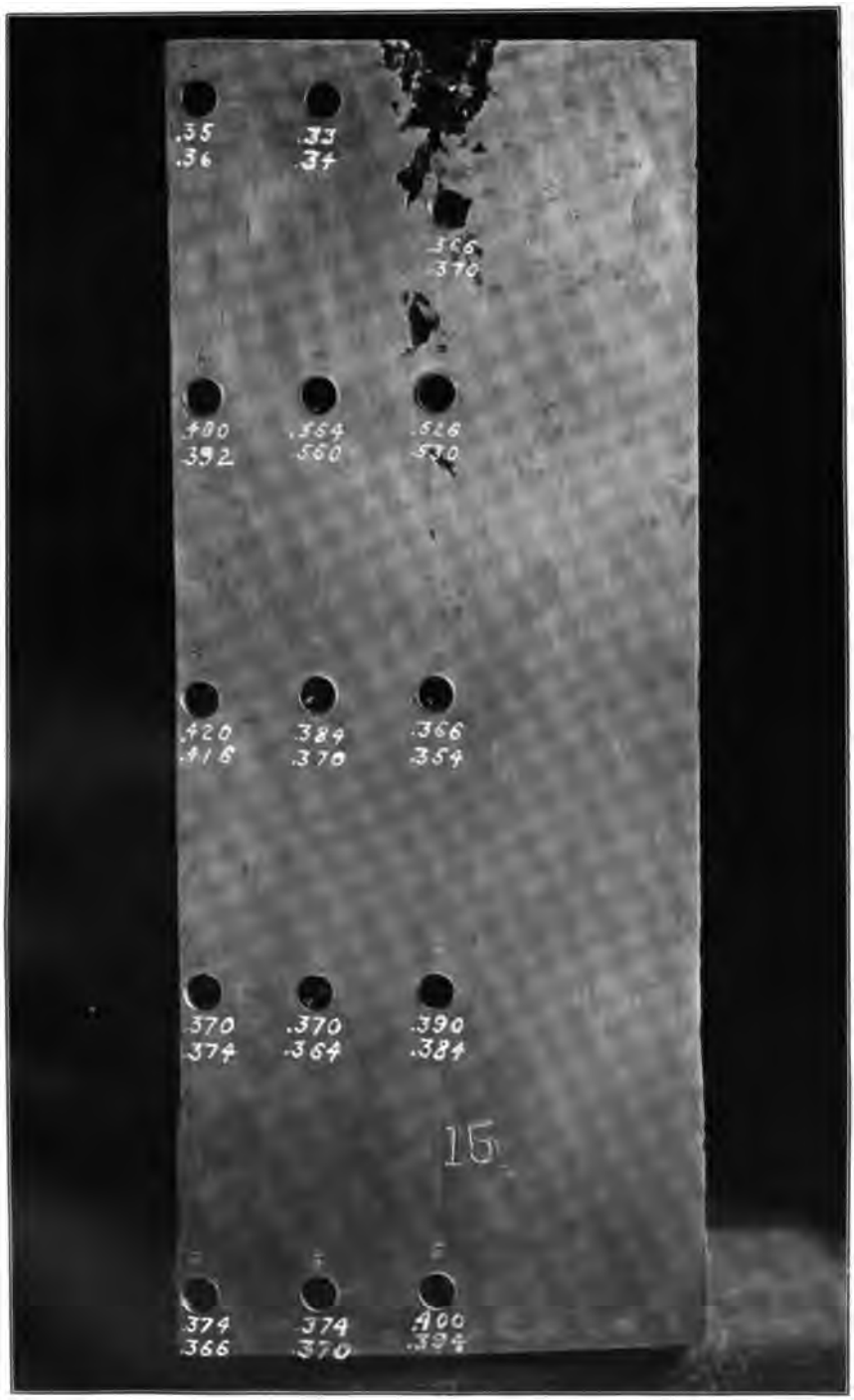


FIG. 41.—INGOT 15. EXPERIMENT 2.

Steel made with 0.15 per cent Al. Vertical section with carbon determinations showing approximately 30 per cent segregation of carbon at the bottom of the pipe and about 30 per cent from the top of the original ingot.

this work. The ends of the silica tube were closed with rubber stoppers, connections being made through one stopper to the pumping system. The other stopper was solid.

At the beginning of the work the thermocouple was placed inside the silica tube, access being made by means of a two-hole stopper, the wires of the couple being fused into glass tubes where they passed through the two-hole stopper. Two disadvantages were present by using this method: (1) The temperature of the interior of the silica tube lagged considerably behind the temperature of the heating unit, thus making accurate control impossible; (2) the occluded gases of the couple and insulating tubes were a source of error.

Since constant temperature was sought rather than actual temperature, the couple was placed between the silica tube and the heating unit, for there the least temperature change in the furnace would show at once and could be corrected by using more or less current as necessary without affecting the temperature inside the tube since a long series of simultaneous readings of temperature in the interior of the silica tube and the space between the silica tube and walls of the furnace showed that at constant temperature the difference was negligible after 10 minutes had elapsed. It seems evident, therefore, that when constant temperature is required over long periods the method used was not only permissible but had certain advantages, among which is convenience of manipulation.

All temperature measurements were made with a platinum-platinum 10 per cent rhodium couple, the E. M. F. being read by a Leeds & Northrup portable potentiometer. This arrangement permits of an accuracy of $\pm 5°$ C.

The pumping system consisted of an oil-sealed pump of the plunger type for rough work and a Toepler mercury pump for the fine work. Either pump could be brought into connection with the tube by manipulation of the stopcocks A and B (fig. 42).

Gases were collected in the collecting bottle of special design shown in the drawing (fig. 42) and from there were drawn to the burette for analysis. The photograph (fig. 43) will give an idea of the apparatus assembled.

The details of an actual typical experiment will next be described, which will be followed by the report of some blank tests.

The specimens used varied in weight from 40 to 50 grams, most of them weighing from 47 to 50 grams.

The sample numbers correspond with the ingot numbers in experiment 2.

A specimen was thoroughly cleaned and washed in benzine and alcohol. After its weight had been determined it was placed in the silica tube. The stopper was inserted and all joints were given a coating of shellac, to insure tightness. The ends of the silica tube were water-cooled to prevent the corks from overheating.

The cock at A was closed and cock B opened. The roughing pump was then operated for 30 minutes. This pump gave on all experiments a vacuum better than 0.1 mm. At the end of 30 minutes B was closed and A opened. Pumping was continued for 30 minutes with the mercury pump. The pinchcock between the collecting bottle and the pump was then closed, the gas in the collecting bottle being driven out by raising the mercury reservoir connected with the latter. The pinchcock was then opened and the heating

current turned on. The heating current was controlled by a carbon block rheostat and an ammeter in the circuit.

The time of heating from atmospheric temperature to 1,000° C. was one hour and this figure was always kept constant.

When the temperature reached 1,000° C., the current was reduced to 5.65 amperes, which maintained the temperature of 1,000° C. within 5° C. The temperature was held there for 10 hours. This constituted one period. At the end of 10 hours the furnace was allowed to cool to atmospheric temperature. Whenever the pressure in the tube rose to 3 mm., the mercury pump was operated and the gas collected. On heating, gases were given off slowly for about 40 minutes and then very rapidly. The period of rapid evolution of gases corresponds evidently with the thermal critical range. The temperature at which the rapid evolution began was apparently between 750° and 850° C.

At the end of a period the gases were passed into a burette and analyzed. The ordinary methods of gas analysis were used.

The above operation was repeated twice, making three periods in all. The gases collected then were the gases given off by three 10-hour periods at 1,000° C. and the gases given off in heating to and cooling from that temperature for three successive times.

It was evident from the work of Baker and others that considerable gas would cling to the sides of the tube even at high vacuums. Several blanks therefore were run with the furnace cold and hot, respectively. The blanks with the cold furnace served to show that the connections were tight. The pressure would rise slightly for 48 hours or more, but from that time on was stationary within the limits of observation.

The blanks on a three-period run were very interesting. The average of three such blanks gave the following result:

	cc.
Period 1	4.1
Period 2	1.2
Period 3	1.1

Average analysis.

CO_2=3.5 per cent.
O=8.5 per cent.
H=3 per cent.
N=85 per cent.

After the apparatus had been used for several determinations, other blanks were run, and as was to be expected the hydrogen content rose to some extent, since it is difficult to remove the last traces of adsorbed hydrogen. Traces of CH_4 were also present.

The data obtained from the several samples has been reduced to standard conditions of 760 mm. pressure and 0° C. Tables for each sample are given (Tables 20–30). In the upper half of each table the cubic centimeters of each gas for each period can be found by passing along the table horizontally after the number of the period. A row is also provided for the sum of the three periods. The last vertical column shows the total volume for each period and also the total volume of gas collected.

The lower half of each table is constructed in the same manner and shows percentage by volume, the last column marked "Total of sum" showing what per cent of the total gas collected was given off in any period.

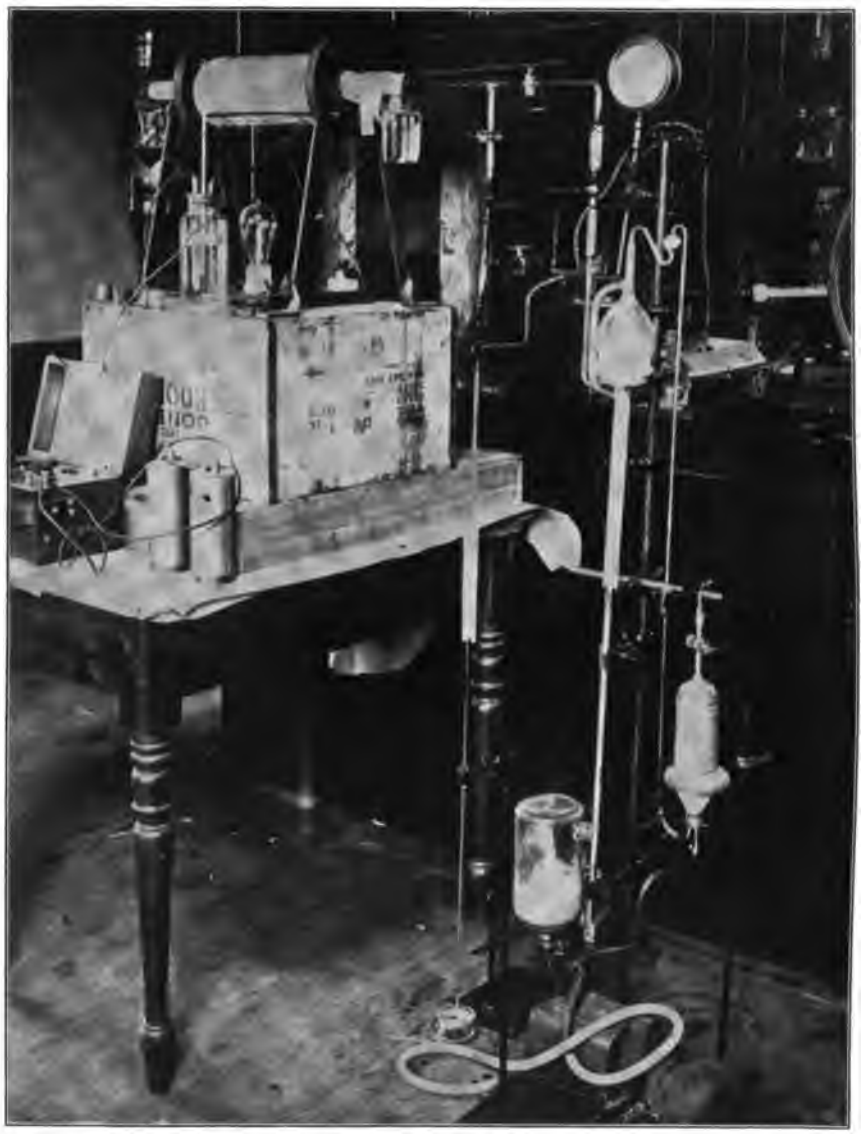


FIG. 43.—ARRANGEMENT OF APPARATUS FOR COLLECTING GASES FROM STEEL SAMPLES, EXPERIMENT 2.

A special table (Table 31) is also provided showing the summation of the results. A column has been introduced showing volume of gas per gram of metal. It has been assumed by Baker and in this report that gas evolved is a function of mass. No doubt this is true to some extent, but the gas evolved may also be a function of the surface exposed.

TABLE 20.—*Sample No. 1, Fe-C-Ti.*

[Weight of sample, 48.39 grams.]

Period.	Volume CO_2.	Volume CO.	Volume CH_4.	Volume H.	Volume N.	Total volume.
	c. c.	c. c.	c. c.	c. c.	c. c.	c. c.
1	0.00	22.23	0.00	23.25	1.12	46.60
2	0.19	10.23	0.19	10.32	0.74	21.67
3	0.00	7.25	0.19	6.98	0.65	15.07
Sum	0.19	39.71	0.38	40.55	2.51	83.34

Period.	CO_2.	CO.	CH_4.	H.	N.	Total of sum.
	Per cent.	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*
1	0.00	47.70	0.00	49.89	2.41	55.41
2	0.88	47.14	0.88	47.56	3.54	26.00
3	0.00	48.83	1.27	46.53	3.87	18.09
Sum	0.23	47.65	0.46	48.66	3.00	100.00

TABLE 21.—*Sample No. 3, Fe-C-Ti.*

[Weight of sample, 51.9679 grams.]

Period.	Volume CO_2.	Volume CO.	Volume CH_4.	Volume H.	Volume N.	Total volume.
	c. c.	c. c.	c. c.	c. c.	c. c.	c. c.
1	0.18	13.89	0.09	14.35	0.92	29.43
2	0.27	3.04	0.09	3.40	0.64	7.44
3	0.09	2.02	0.00	2.39	0.83	5.33
Sum	0.54	18.95	0.18	20.14	2.39	42.20

Period.	CO_2.	CO.	CH_4.	H.	N.	Total of sum.
	Per cent.	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*
1	0.61	47.13	0.31	48.76	3.19	69.74
2	3.63	40.86	1.21	45.70	8.60	17.63
3	1.69	37.90	0.00	44.84	15.57	12.63
Sum	1.28	44.90	0.43	47.72	5.67	100.00

TABLE 22.—*Sample No. 5 (Fe-Mn).*

[Weight of sample, 50.5972 grams.]

Period.	Volume CO_2.	Volume CO.	Volume CH_4.	Volume H.	Volume N.	Total volume.
	c. c.	c. c.	c. c.	c. c.	c. c.	c. c.
1	0.00	22.32	0.37	22.41	1.21	46.31
2	0.00	7.91	0.09	7.91	0.65	16.56
3	0.00	5.98	0.14	6.16	0.64	12.92
Sum	0.00	36.21	0.60	36.48	2.50	75.79

Period.	CO_2.	CO.	CH_4.	H.	N.	Total of sum.
	Per cent.	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*
1	0.00	48.20	0.80	48.39	2.51	61.95
2	0.00	47.76	0.54	47.76	3.94	21.85
3	0.00	46.29	1.09	47.69	4.93	16.20
Sum	0.00	47.77	0.79	48.13	3.31	100.00

TABLE 23.—*Sample No. 8 (Fe-Ti carbonless).*

[Weight of sample, 47.6817 grams.]

Period.	Volume CO_2.	Volume CO.	Volume CH_4.	Volume H.	Volume N.	Total volume.
	c. c.	c. c.	c. c.	c. c.	c. c.	c. c.
1	0.09	17.93	0.00	19.57	0.64	38.23
2	0.00	5.92	0.00	6.64	0.55	13.11
3	0.19	3.16	0.09	3.72	0.65	7.81
Sum	0.28	27.01	0.09	29.93	1.84	59.15

Period.	CO_2.	CO.	CH_4.	H.	N.	Total of sum.
	Per cent.	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*
1	0.23	46.90	0.00	51.19	1.91	64.63
2	0.00	45.15	0.00	50.65	4.20	22.16
3	2.43	40.46	1.15	47.63	8.33	13.21
Sum	0.47	45.66	0.15	50.60	3.12	100.00

TABLE 24.—*Specimen No. 9 (Fe-Ti carbonless).*

[Weight of sample, 46.4439 grams.]

Period.	Volume CO_2.	Volume CO.	Volume CH_4.	Volume H.	Volume N.	Total volume.
	c. c.	c. c.	c. c.	c. c.	c. c.	c. c.
1	0.00	18.58	0.14	19.50	0.97	39.19
2	0.00	4.05	0.09	4.42	0.74	9.30
3	0.09	3.28	0.09	3.91	0.82	8.10
Sum	0.09	25.91	0.32	27.83	2.53	56.59

Period.	CO_2.	CO.	CH_4.	H.	N.	Total of sum.
	Per cent.	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*
1	0.00	47.41	0.36	49.75	2.48	69.24
2	0.00	43.55	0.96	47.53	7.96	16.43
3	1.11	40.49	1.11	48.27	9.02	14.33
Sum	0.16	45.78	0.57	49.17	4.32	100.00

TABLE 25.—*Sample No. 12 (Fe-Si).*

[Weight of sample, 47.0992 grams.]

Period.	Volume CO_2.	Volume CO.	Volume CH_4.	Volume H.	Volume N.	Total volume.
	c. c.	c. c.	c. c.	c. c.	c. c.	c. c.
1	0.00	15.64	0.24	17.02	1.14	34.04
2	0.00	3.68	0.28	3.86	1.10	8.92
3	0.00	3.59	0.00	4.32	0.64	8.55
Sum	0.00	22.91	0.52	25.20	2.88	51.51

Period.	CO_2.	CO.	CH_4.	H.	N.	Total of sum.
	Per cent.	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*
1	0.00	46.00	0.71	50.06	3.23	66.09
2	0.00	41.35	3.14	43.37	12.14	17.32
3	0.00	41.99	0.00	50.53	7.48	16.59
Sum	0.00	44.49	1.01	48.93	5.57	100.00

TABLE 26.—*Sample No. 13 (Al).*

[Weight of sample, 47.9093 grams.]

Period.	Volume CO_2.	Volume CO.	Volume CH_4.	Volume H.	Volume N.	Total volume.
	c. c.	*c. c.*	*c. c.*	*c. c.*	*c. c.*	*c. c.*
1	0.09	19.02	0.00	20.66	0.82	40.59
2	0.09	6.64	0.27	7.28	0.73	15.01
3	0.09	3.37	0.00	4.91	0.09	8.46
Sum	0.27	29.03	0.27	32.85	1.64	64.06

Period.	CO_2.	CO.	CH_4.	H.	N.	Total of sum.
	Per cent.	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*
1	0.22	46.85	0.00	50.89	2.04	63.42
2	0.60	44.27	1.80	48.53	5.60	23.43
3	1.06	39.65	0.00	57.76	1.53	13.15
Sum	0.42	45.36	0.42	51.33	2.47	100.00

TABLE 27.—*Sample No. 15 (Al).*

[Weight of sample, 47.2004 grams.]

Period.	Volume CO_2.	Volume CO.	Volume CH_4.	Volume H.	Volume N.	Total volume.
	c. c.	*c. c.*	*c. c.*	*c. c.*	*c. c.*	*c. c.*
1	0.09	15.07	0.11	16.00	1.02	32.29
2	0.09	5.30	0.09	5.77	0.65	11.90
3	0.00	5.21	0.00	6.51	0.65	12.37
Sum	0.18	25.58	0.20	28.28	2.32	56.56

Period.	CO_2.	CO.	CH_4.	H.	N.	Total of sum.
	Per cent.	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*
1	0.21	46.66	0.34	49.53	3.26	57.09
2	0.75	44.54	0.76	48.49	5.46	21.04
3	0.00	42.12	0.00	52.63	5.25	21.87
Sum	0.32	45.23	0.35	50.00	4.10	100.00

TABLE 28.—*Sample No. 17-1 (raw converter metal).*

[Weight of sample, 40.1734 grams.]

Period.	Volume CO_2.	Volume CO.	Volume CH_4.	Volume H.	Volume N.	Total volume.
	c. c.	*c. c.*	*c. c.*	*c. c.*	*c. c.*	*c. c.*
1	0.18	14.72	1.75	16.00	1.01	33.66
2	0.28	4.78	0.28	4.78	0.83	10.95
3	0.09	3.72	0.00	3.81	0.56	8.18
Sum	0.55	23.22	2.03	24.59	2.40	52.79

Period.	CO_2.	CO.	CH_4.	H.	N.	Total of sum.
	Per cent.	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*
1	0.53	43.73	5.26	47.54	2.94	63.75
2	2.56	43.65	2.56	43.65	7.58	20.74
3	1.10	45.50	0.00	46.58	6.72	15.51
Sum	1.04	43.98	3.84	46.59	4.55	100.00

TABLE 29.—*Sample 18–1 (steel without deoxidizer).*

[Weight of sample, 46.3198 grams.]

Period.	Volume CO_2.	Volume CO.	Volume CH_4.	Volume H.	Volume N.	Total volume.
	c. c.	*c. c.*	*c. c.*	*c. c.*	*c. c.*	*c. c.*
1	0.74	15.44	0.37	14.97	1.49	33.01
2	0.09	5.21	0.09	5.77	0.65	11.81
3	0.09	3.72	0.19	4.01	0.85	8.85
Sum	0.92	24.37	0.65	24.75	2.98	53.67

Period.	CO_2.	CO.	CH_4.	H.	N.	Total of sum.
	Per cent.	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*
1	2.24	46.78	1.12	45.36	4.50	61.45
2	0.76	44.15	0.76	48.89	5.46	21.99
3	1.02	42.04	2.15	45.32	9.47	16.56
Sum	1.71	45.38	1.21	46.09	5.61	100.00

TABLE 30.—*Sample 18–2 (steel without deoxidizer).*

[Weight of sample, 40.4437 grams.]

Period.	Volume CO_2.	Volume CO.	Volume CH_4.	Volume H.	Volume N.	Total volume.
	c. c.	*c. c.*	*c. c.*	*c. c.*	*c. c.*	*c. c.*
1	0.00	16.74	0.12	16.93	1.30	35.09
2	0.00	3.81	0.00	4.09	0.86	8.76
3	0.00	3.44	0.00	4.56	0.09	8.09
Sum	0.00	23.99	0.12	25.58	2.25	51.94

Period.	CO_2.	CO.	CH_4.	H.	N.	Total of sum.
	Per cent.	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*
1	0.00	47.69	0.34	48.23	3.74	67.56
2	0.00	43.49	0.00	46.69	9.82	16.86
3	0.00	42.47	0.00	56.29	1.24	15.58
Sum	0.00	46.11	0.23	49.25	4.41	100.00

TABLE 31.—*Complete data on 30-hour run.*

Number of sample.	CO_2.	CO.	CH_4.	H.	N.	Total volume of gas.	Weight of sample.	Gas per gram metal.
	Per ct.	*Per ct.*	*Per ct.*	*Per ct.*	*Per ct.*	*c. c.*	*Grams.*	*c. c.*
1	0.23	47.65	0.46	48.66	3.00	83.34	48.3900	1.72
3	1.28	44.90	0.43	47.72	5.67	42.20	51.9679	.81
5	0.00	47.77	0.79	48.13	3.31	75.79	50.5972	1.49
8	0.47	45.66	0.15	50.60	3.12	59.15	47.6817	1.24
9	0.16	45.78	0.57	49.17	4.32	56.59	46.4439	1.22
12	0.00	44.49	1.01	48.93	5.57	51.51	47.0992	1.09
13	0.42	45.36	0.42	51.33	2.47	64.06	47.9093	1.34
15	0.32	45.23	0.35	50.00	4.10	56.56	47.2004	1.19
17–1	1.04	43.98	3.84	46.59	4.55	52.79	40.1734	1.31
18–1	1.71	95.38	1.21	46.09	5.61	53.67	46.3198	1.16
18–2	0.00	46.11	0.23	49.25	4.41	51.94	40.4437	1.28

Evolution curves are also shown (charts 2–12) in which the rise of pressure per hour is plotted against total time elapsed at 1000° C. The first hour of heating is included in these curves. It seems that

the rate of gas evolution must be equally as important as the total gas occluded since upon it depends the ease with which the gas may be driven off in practice. As an illustration, compare samples 15 and 18–1. Sample 18–1 gave 1.16 cc. per gram of metal and sample 15, 1.19 cc. per gram. On comparing the evolution curves it is very evident that sample 15 at the end of 31 hours is yielding gas at a rate of 2.2 mm. rise of pressure per hour, whereas 18–1 is yielding gas at the rate of 0.9 mm. rise of pressure per hour. In other words, 18–1 gave up its gas very readily and at the end of the third period was nearly exhausted; 15 did not give up its gas readily, but maintains a steady output.

Samples 1 and 3 were cast with the same deoxidizer. It is very evident that they do not check. One gives 1.72, the other 0.81 cc. per gram.

Evolution curves for samples 1 and 3 are as different as the gas yielded per gram of metal. Sample 1 is yielding gas at twice the rate of sample 3 at the end of 30 hours.

Sample 5 gave a high gas yield also. It gave off gas rapidly at first, did not fall suddenly, and at the end of the third period was producing gas at the rate of 1.8 mm. rise in pressure per hour.

Samples 8 and 9 checked well in regard to gas per gram, sample 8 giving 1.24 cc. and sample 9 giving 1.22 cc. per gram. The evolution curves do not check as well. No. 9 did not yield gas as readily as No. 8 for the first two hours, but No. 8 dropped suddenly, whereas 9 dropped more slowly, giving a very smooth, even curve.

Sample 12 yielded 1.09 cc. per gram. Its evolution curve resembles very much that of sample 3. At the end of the third period the rate is low and is gradually decreasing.

Samples 13 and 15 are also to be compared; No. 13 gives 1.34 cc. per gram, No. 15, 1.19 cc. per gram. No. 13 has a lower rate at the end of the third period than No. 15 regardless of the fact that No. 15 has yielded at the end of 30 hours less gas than sample 13. Both 13 and 15 have a high rate at the end of the third period, which would lead one to think that at the end of 100 hours, for example, they would give a higher yield per gram of metal as compared with 3 or 12 than would appear at the end of a 30-hour run.

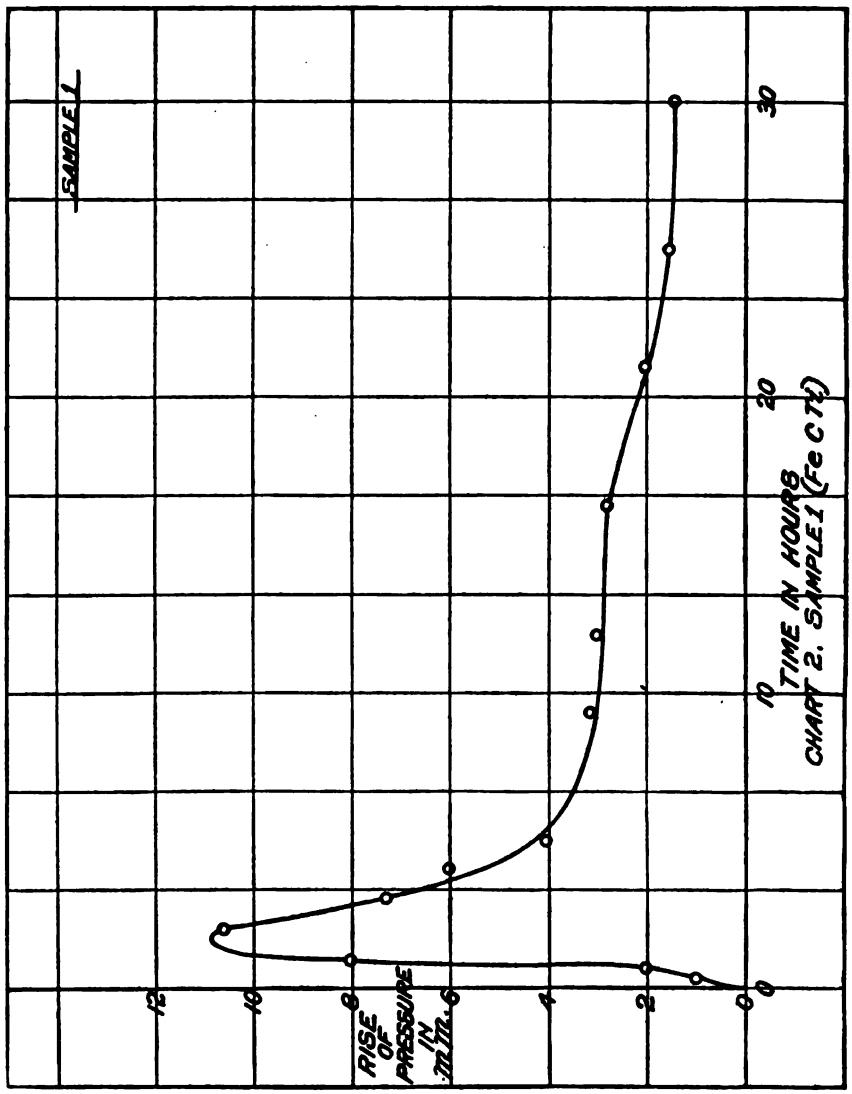
Sample 17–1, which was very full of blowholes, gave 1.31 cc. per gram of metal. Its evolution curve has a peculiar form. The rate of evolution did not drop as suddenly as most of the other samples. Although the maximum is not as high as others, it is maintained longer. At the end of the third period the rate was still rather high.

Samples 18–1 and 18–2 gave 1.16 and 1.28 cc. per gram. Their evolution curves are very much alike and show a low rate at the end of the third period.

An inspection of the assembled data brings out many interesting observations, a few of which can be mentioned.

Samples 8 and 9 not only check as to volume of gas per gram, but also as to composition of gas: CO, 45.66 per cent and 45.78 per cent; H, 50.60 per cent and 49.17 per cent. The hydrogen is higher in this series than in any other excepting samples 13 and 15.

Samples 13 and 15 both run over 50 per cent hydrogen, which is very high, their CO contents checking at 45.36 and 45.23.


SAMPLE 1
RISE OF PRESSURE IN m/m.
0
2
4
6
8
10
12
0
10
20
30
TIME IN HOURS
CHART 2. SAMPLE 1 (Fe C Tt)

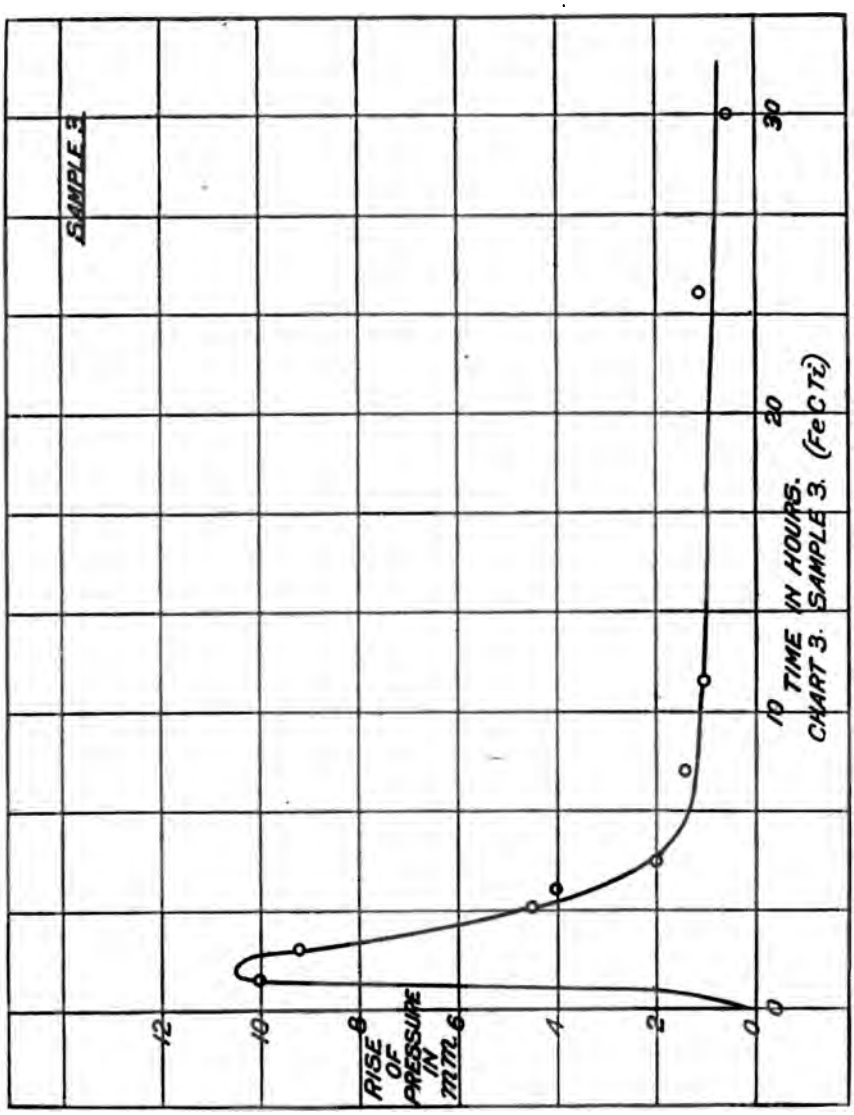


CHART 3. SAMPLE 3. ($FeCTi$)

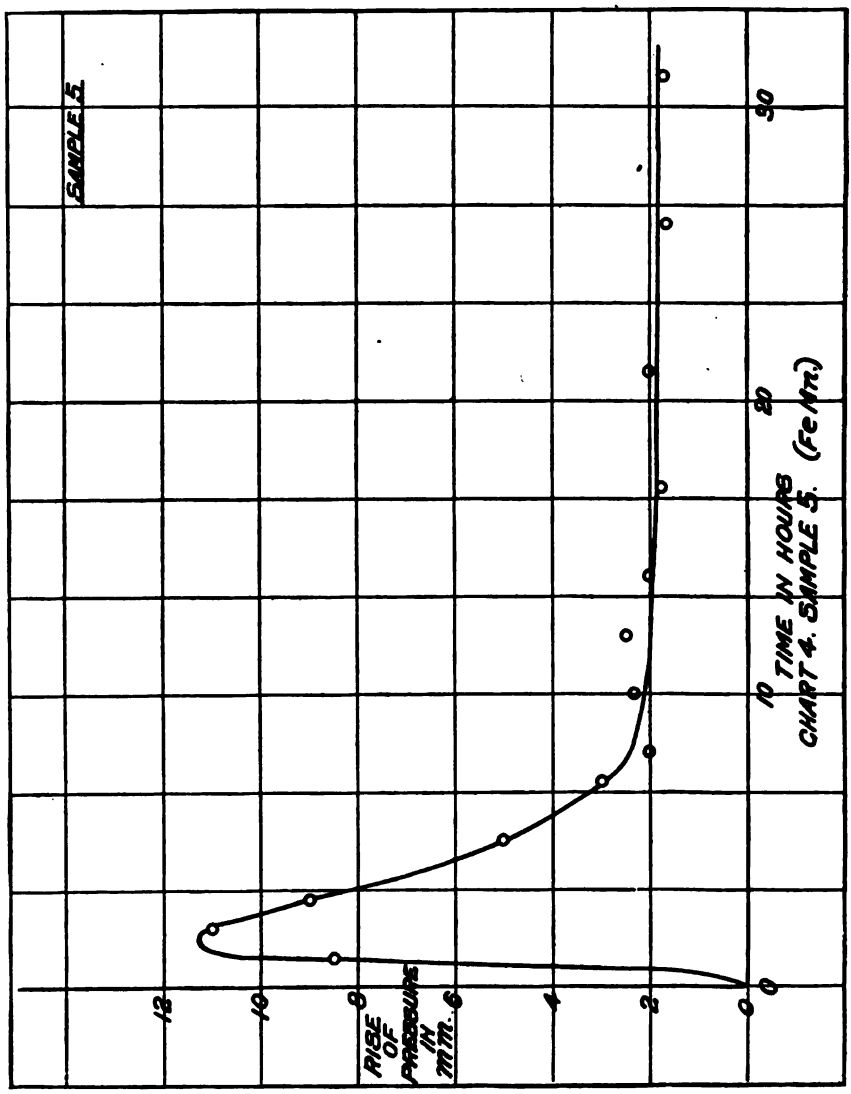


CHART 4. SAMPLE 5. (Fe/Mn.)

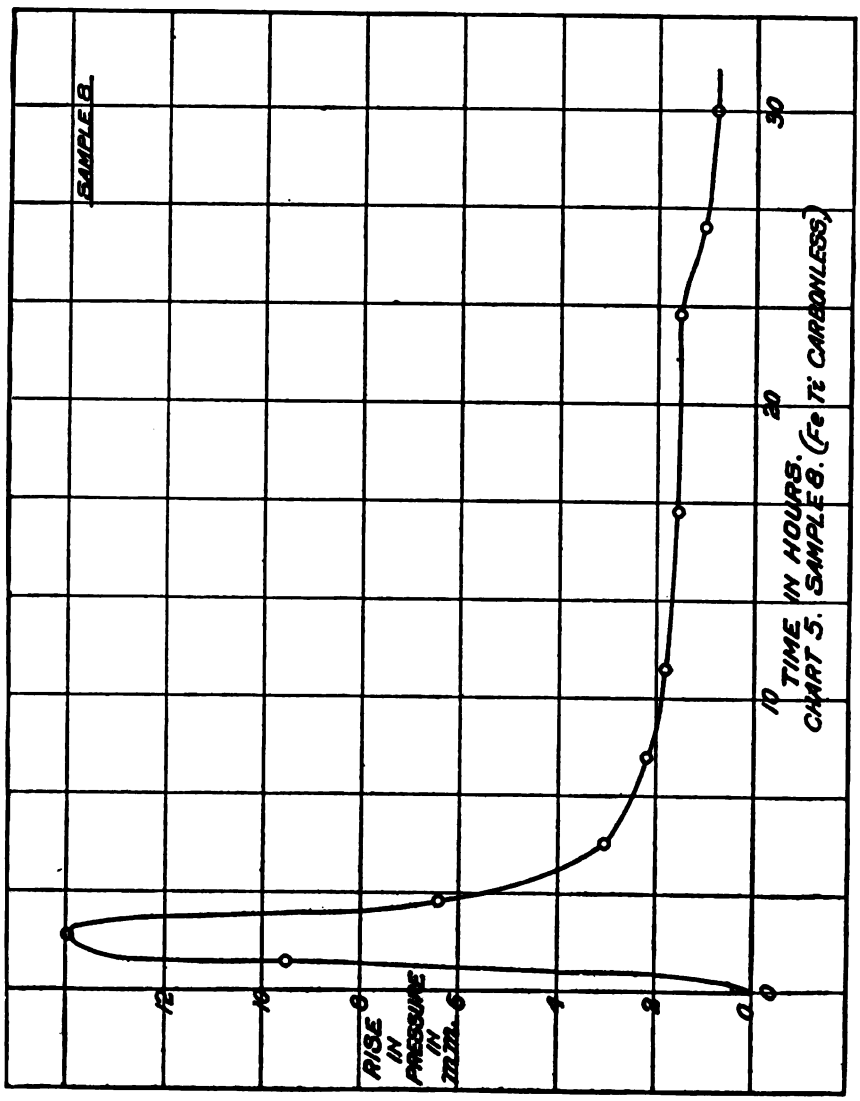
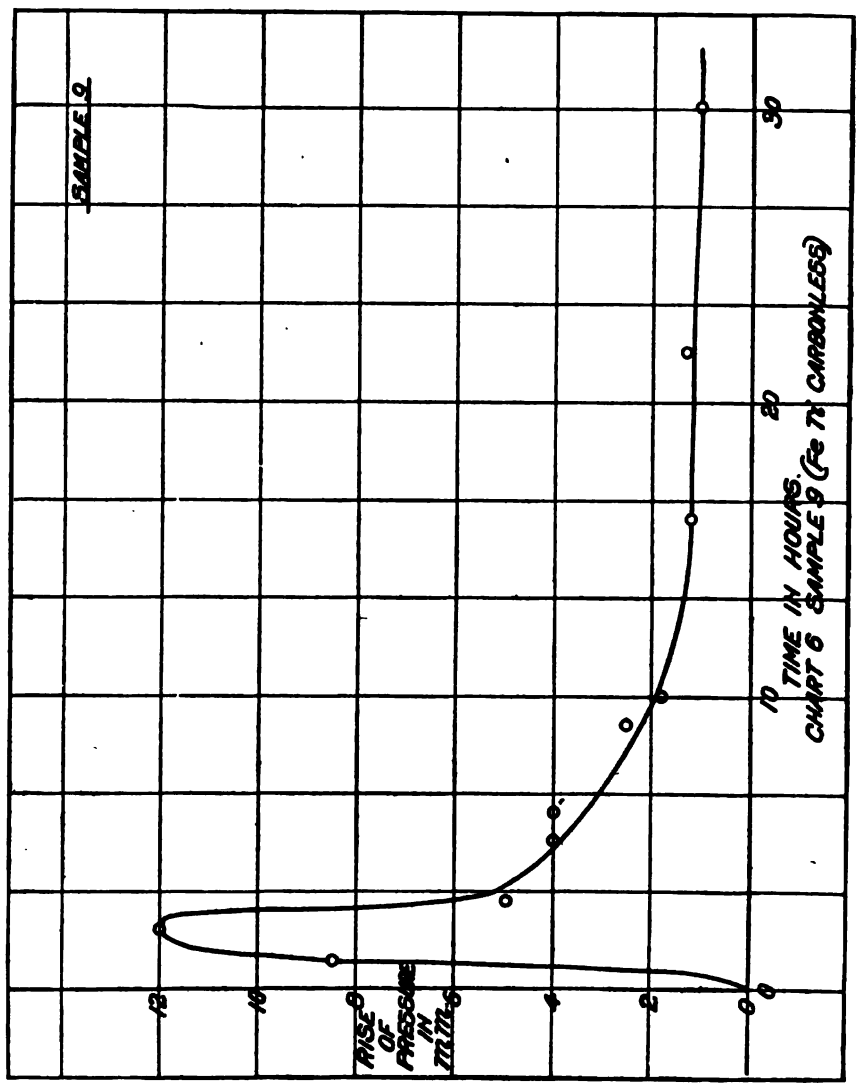


CHART 5. SAMPLE B. (Fe Ti CARBONLESS)


SAMPLE 9
RISE OF PRESSURE IN m/m
12
16
8
4
2
0
10
20
30
TIME IN HOURS.
CHART 6 SAMPLE 9 (Fe 7% CARBONLESS)

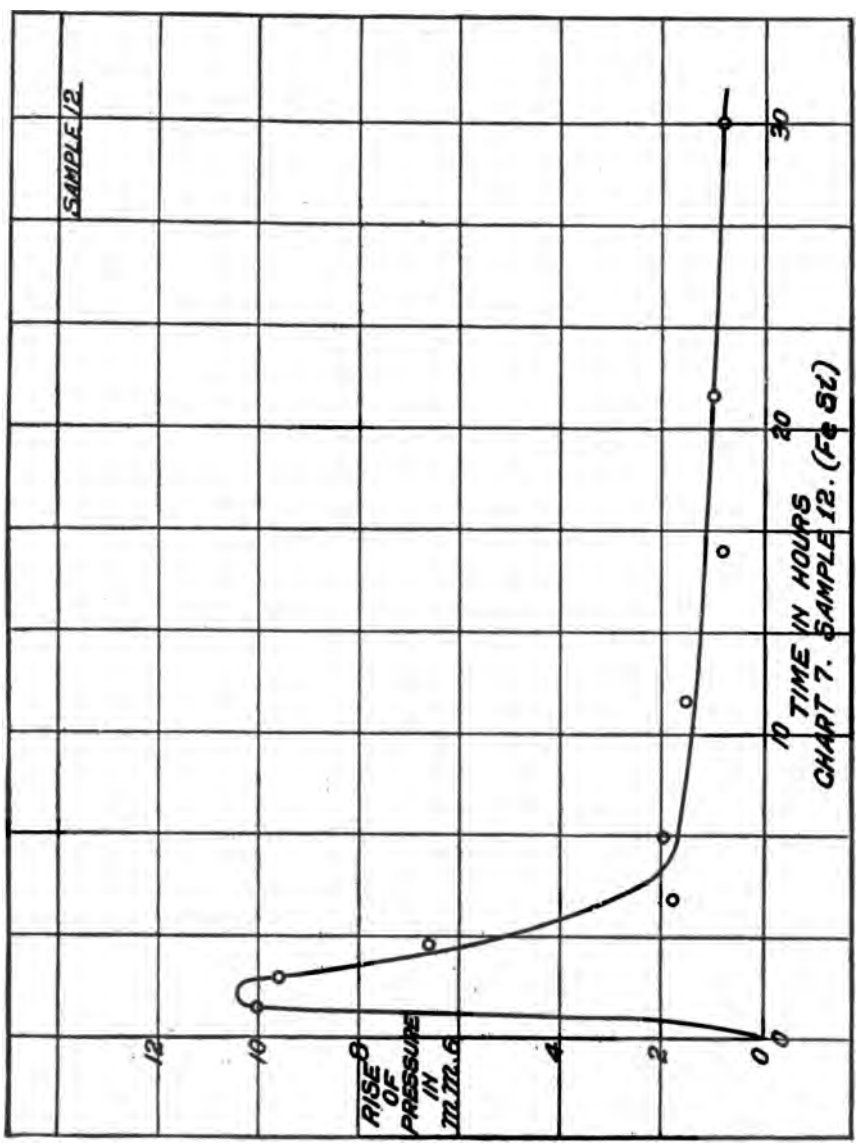
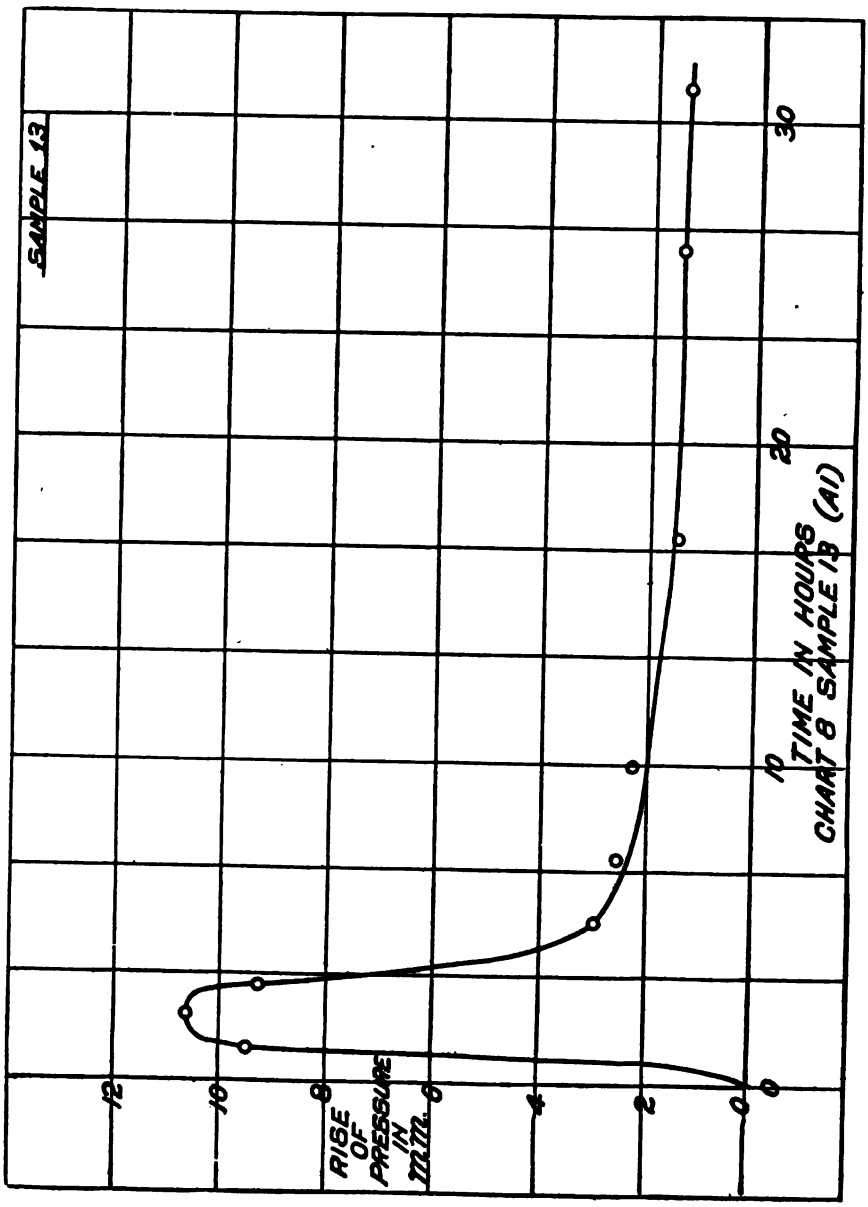
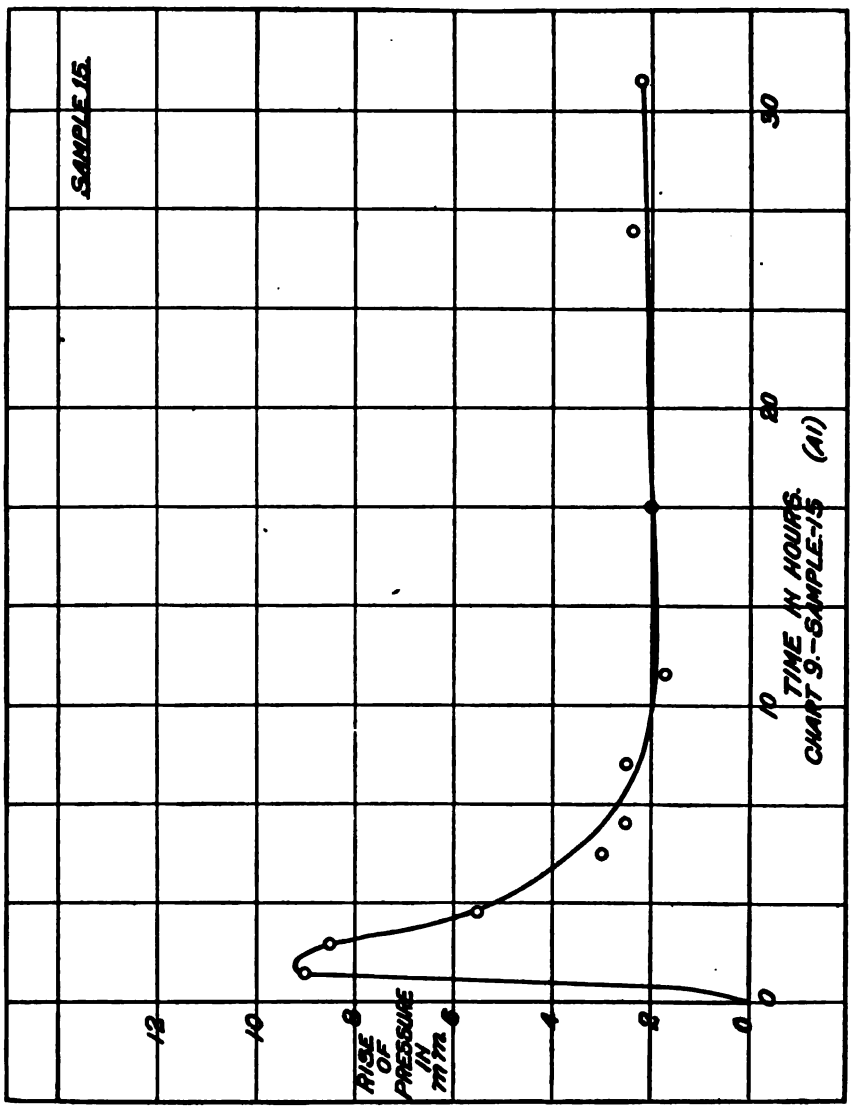


CHART 7. SAMPLE 12. (Fe St)


SAMPLE 13
RISE OF PRESSURE IN m/m.
0
2
4
6
8
10
12
0
10
20
30
TIME IN HOURS
CHART 8 SAMPLE 13 (A1)


SAMPLE 15.
RISE OF PRESSURE IN m/m
0
2
4
6
8
10
12
0
10
20
30
TIME IN HOURS.
CHART 9.-SAMPLE-15 (A1)

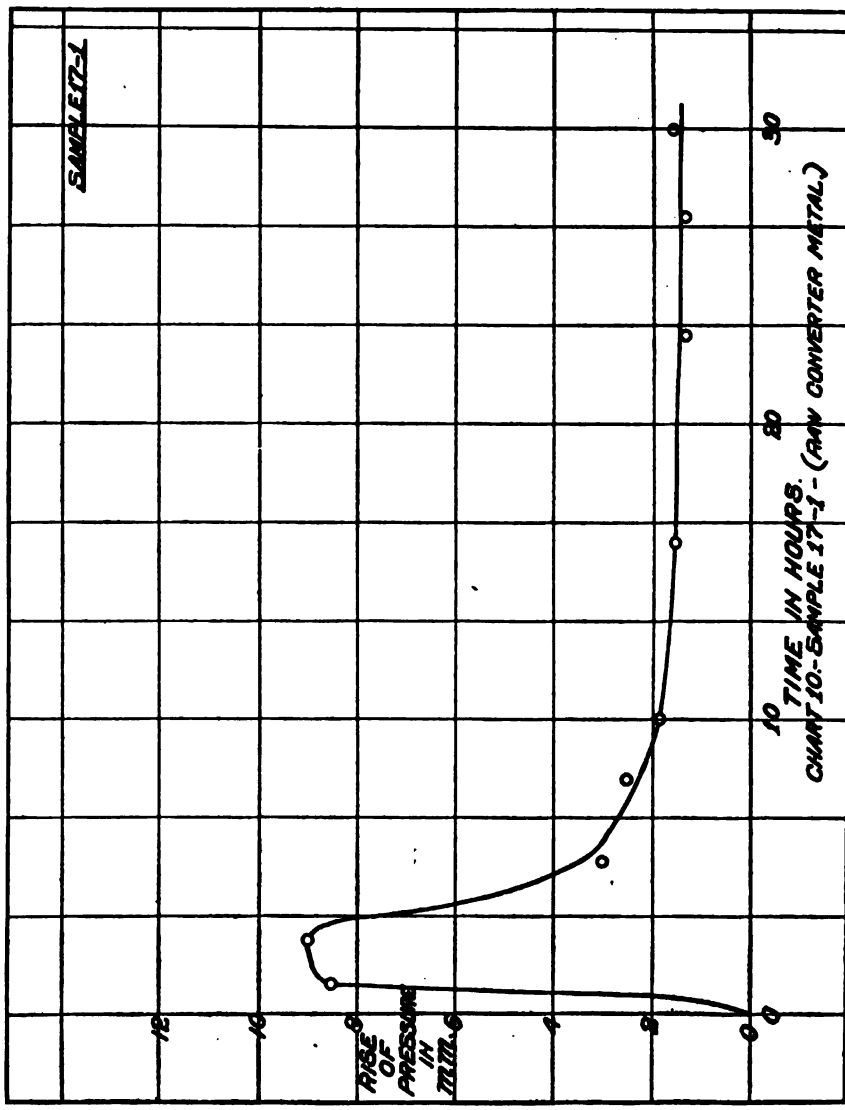
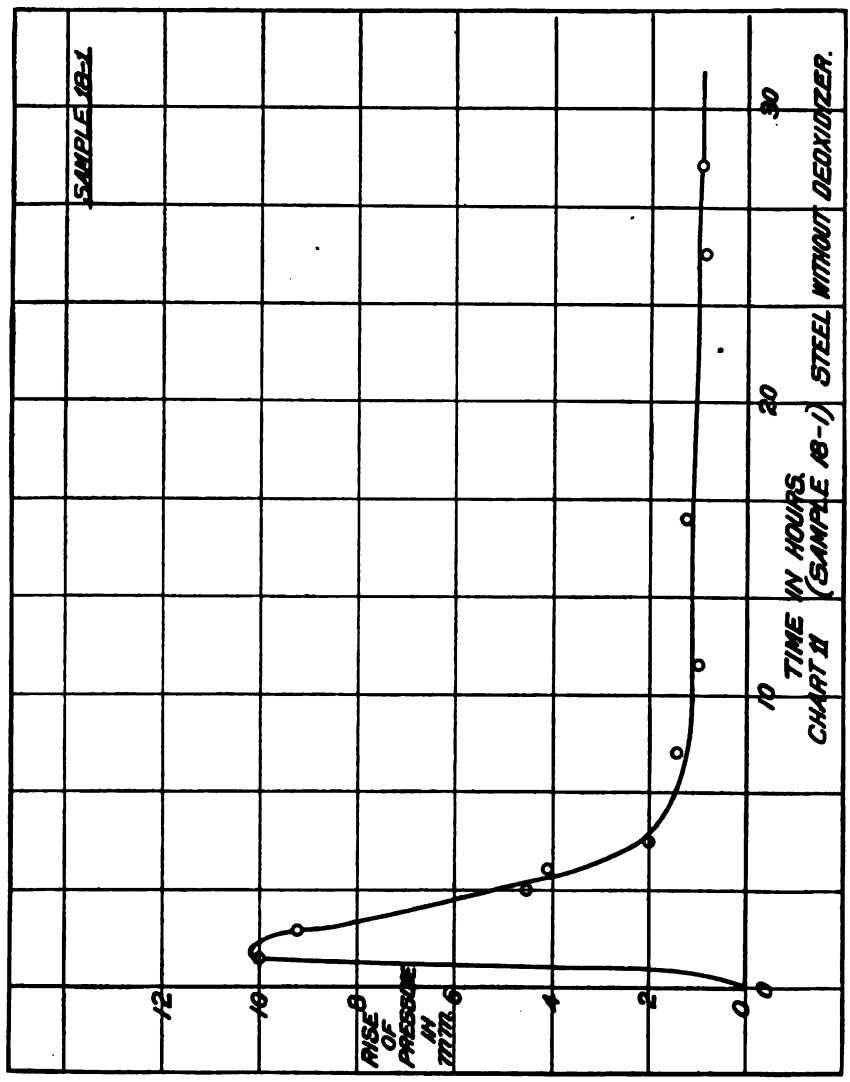


CHART 10-SAMPLE 17-1 - (RAW CONVERTER METAL.)


SAMPLE 18-1
RISE OF PRESSURE IN mm. Hg
0
2
4
6
8
10
12
0
10
20
30
TIME IN HOURS.
CHART II (SAMPLE 18-1) STEEL WITHOUT DEOXIDIZER.

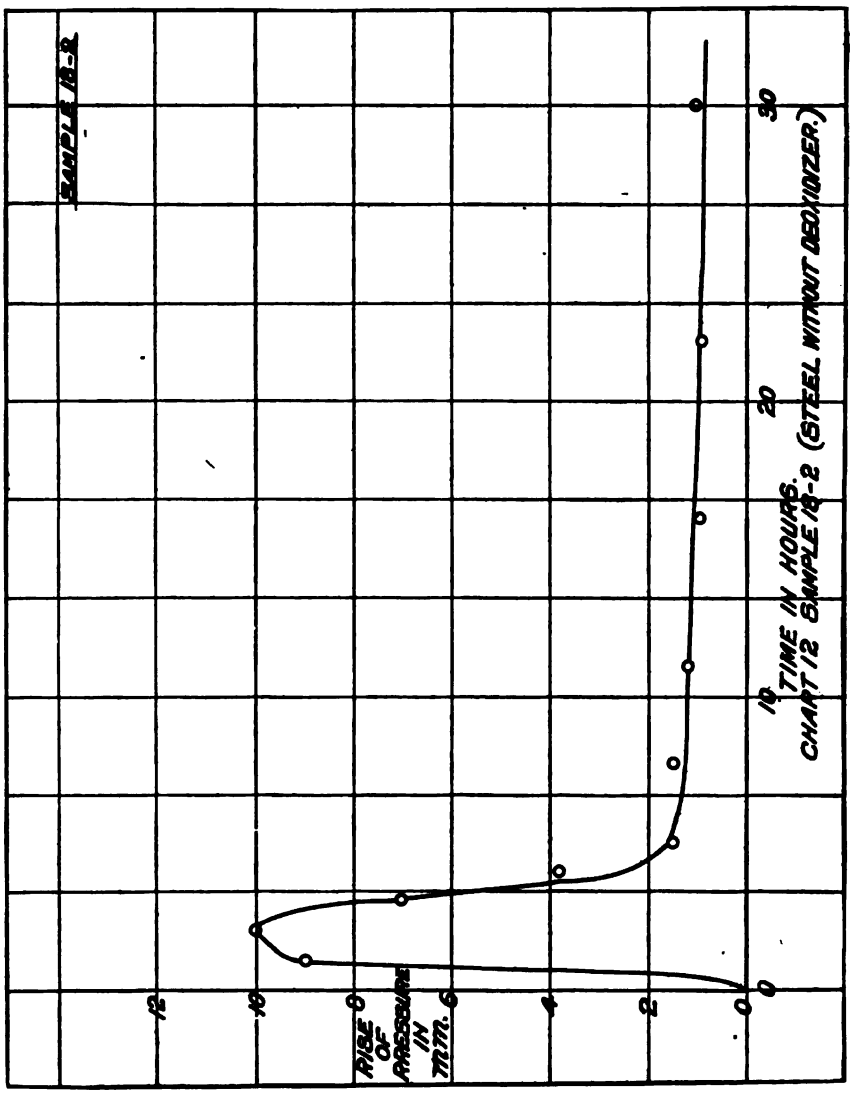


CHART 12 SAMPLE 12-2 (STEEL WITHOUT DEOXIDIZER.)

The following table may be of some interest. Column 1 has the samples arranged in order of volume given off per gram. Column 2 has the samples arranged in order of per cent H; column 3, in order of per cent CO:

TABLE 32.

Volume per gram, decreasing from top to bottom.	Per cent H, decreasing from top to bottom.	Per cent CO, decreasing from top to bottom.
1	13	5
5	8	1
13	15	18-2
17-1	18-2	9
18	9	8
8	12	18-1
9	1	13
15	5	15
18-1	3	3
12	17-1	12
3	18-1	17-1

These figures appear without any apparent relation, but a little order can be brought into the chaos as follows:

Sample 1 can be rejected, as its evolution curve, as well as the volume per gram, seems irregular. Taking the means of the various groups of ingots with the same deoxidizer and arranging in order of cc. per gram, we have:

TABLE 33.—*Relative order of ingots as regards gases evolved.*

Ingot number.	Cc. per gram, decreasing from top down.	Deoxidizer used.
5	1.49	Fe-Mn.
17-1	1.31	Raw converter metal.
(13 and 15)	1.27	Al
(8 and 9)	1.23	Fe-Ti (carbonless).
(18-1, 18-2)	1.22	Steel without deoxidizer.
12	1.09	Fe-Si
3	0.81	Fe-C-Ti

Evidently, if any valuable conclusions are to be drawn from gas extraction work, there must be many more tests made from various parts of the ingot.

Comparing the average of ingots 13 and 15 made with aluminum in these experiments and ingots 18–1 and 18–2, representing steel without any special deoxidizer besides the ferro-silicon and ferro-manganese needed for the analysis sought, we find that steel with aluminum gave 1.27 total gases per gram of steel, while the steel without aluminum gave 1.22 total gases per gram of steel, whereas it will be remembered that Baker's steel with aluminum gave 1.33 cc. total gases per gram of steel, while his unsound steel gave 0.665 total gases per gram of steel. It should be added that Baker tried as far as possible to open all the blowholes in his unsound steel and let out the gases contained in the holes, while no attempt was made to do this in these experiments. It should also be noted that the raw converter metal, while very unsound, gave 1.31 cc. total gases per gram of steel, or more than any of the other ingots with the exception of ingot 5 made with ferro-manganese as a deoxidizer.

DISCUSSION OF RESULTS.

The preliminary experiments indicate the possibility of better results obtained from adding the deoxidizer to the raw converter metal before recarburization. This is a radical change from common practice, but the indications are plain that such a method might lead to valuable results.

The results of experiment 1, where no recarburizer was added, show a distinct difference in the effect of the different deoxidizers and also a difference in the various proportions of the same deoxidizer. Chart 1 and the photographs, figures 11–28, show this plainly.

Experiment 2.—It is not entirely certain that the best proportion of each deoxidizer was used in this experiment, but some limit had to be drawn as to the number of proportions tried in experiment 1. In two cases (Fe–C–Ti and Fe–Ti carbonless) the proportion used was that recommended by the manufacturers in addition to being the proportion giving the soundest ingots in experiment 1, while the proportion of aluminum (0.14 per cent or about 45 ounces per ton of steel) is about one and a half times as much as the largest percentage of aluminum recommended by the manufacturer, although from chart 1 it will be seen that 0.2 per cent aluminum, which was the amount aimed for in experiment 2, gave an average relative density of over 7.93. For silicon and manganese no recommendations could be obtained from manufacturers, and proportions recommended by various metallurgists were used in experiment 1 and the proportion giving the soundest ingots in that experiment was used in experiment 2.

As in the preliminary experiments, the raw converter metal was comparatively free from blowholes (see figs. 1, 5, and 35). All of the ingots in experiment 2 except 17 and 18 were much sounder than those in experiment 1, as might have been expected.

Density.—Both the density and the specific gravity tests were rather disappointing. To obtain good results in measurements of density it is believed that ingots must be weighed, either with the pipe left open or after cropping off the piped portion. In experiments like the present one, specific gravity tests from small specimens, unless taken from many places in the same ingot and averaged, are of little value.

Tensile tests.—It will be noticed from Tables 13 and 15 that the order of the deoxidizer as regards tensile strength is exactly the same whether taken from the annealed cast metal or the annealed forged metal, although of course the actual strength figures are much higher in the forged material than in the cast condition. The elongation figures do not check so well, but again, as would be expected, those for the forged metal are much superior to those of the cast metal.

Impact tests.—The annealed forged steel is also much more resistant to impact shocks than the annealed cast steel, but the relative order of the deoxidizers as regards the Charpy tests is almost diametrically opposite in the cast and forged material.

Segregation.—There is little doubt as to the proper order of the deoxidizer as regards its influence on carbon segregation so far as these tests went (see Table 18).

Gas extraction tests.—Baker's results, showing a large difference between the gases given off from steel with and without aluminum,

were not checked in these experiments although the conditions were somewhat different.

It is not clear that the steel which gives off the most gases in such a gas test as this is necessarily the most sound or the most unsound material. Practically all of the gas test pieces in this experiment were sound on the outside at least and the identical pieces used for the specific gravity tests (Table 11) were used in the gas tests, yet there is no direct relation shown between these two tests; for instance, the ingots cast with Fe–Ti carbonless gave the highest average specific gravity, while the samples with Fe–Mn and Al additions both gave out more gases. There are two cases where deoxidizers might affect the evolution of gases; (1) in the molten steel and (2) in the steel during solidification. An ideal deoxidizer presumably would be one which would allow the maximum amount of gases to be given off from the molten steel while preventing such gases as remained in the steel from being given off during solidification. It is not clear that the tests which have been made are a measure of the influence of the deoxidizers in either of the above cases, for they give no information as to the relative amount of gases evolved from the molten steel and from the steel during solidification. The tests do show, however, that some of the deoxidizers, notably Fe–Mn and Al, do favor the retention in solid solution of such gases as remain in the steel after it has begun to solidify.

Microscopic examination.—Preliminary microscopic examination was made from the tensile test specimens, which showed a considerable amount of slag present, as might have been expected from the small size of ingot used and because no special precautions were taken in pouring to keep the slag out of the mold. The irregularity of the slag has doubtless affected the physical properties, and a great many more physical tests should be made from these ingots if valuable conclusions are to be drawn from them. It is hoped to make further microscopic examination with a view to throwing more light on the irregularity of the physical tests in experiment 2, but the results will have to be published in a later report.

Cost of deoxidizers.—The question of cost is of great interest to the manufacturer. The following table (34) will show the relative cost of the deoxidizers per ton of steel. The normal price of the deoxidizers rather than the war price is used, although the author realizes that prices of ferro-manganese and aluminum have been almost tripled during 1915.

TABLE 34.—*Calculation of cost of deoxidizers per ton of steel.*

[Based on experiment 2.]

Deoxidizer.	Ounces deoxidizer used per ton of steel (see Table 9).	Normal price of deoxidizer.	Cost of deoxidizer per ton of steel.
Fe–C–Ti	212	$0.10 per pound	$1.33
Fe–Mn	198	$39.65 per ton	.25
Fe–Ti, carbonless	125	$0.30 per pound	2.31
Fe–Si	229	$71.12 per ton	.51
Al	46	$0.19 per pound	.55

Density as measured by the number of blowholes in vertical sections, figures 30–34, inclusive.—Ignoring the pipe, the density as measured by the lack of blowholes in the vertical sections of the ingots gives the following order, No. 1 being the group of ingots most free from blowholes. In the same table is given the relative order of deoxidizer as regards influence on piping.

TABLE 35.—*Order of deoxidizers as regards soundness and piping.*

Deoxidizer.	Relative order of deoxidizer as regards soundness.	Relative order of deoxidizer as regards piping.
Fe-C-Ti	4	[1]1
Fe-Mn	5	4
Fe-Ti, carbonless	3	5
Fe-Si	2	2
Al	1	3

[1] The group of ingots with the smallest pipe is designated as No. 1.

CONCLUSIONS.

It was not to be expected that any very startling difference would be noticed in the action of the deoxidizers tested. If there were such a difference, it is reasonable to suppose that manufacturers would be more unanimous in choosing one or more of them to the exclusion of the others.

The evidence obtained in these experiments, either on account of the small number of tests or because of experimental difficulties, is not conclusive, but the results of the various tests are collected below in Table 36 and give a graphic idea of the influence of the deoxidizers tested. Their relative merits, however, depend so much on just what is sought in the steel that each manufacturer must really decide for himself which deoxidizer will best suit his needs.

TABLE 36.—*Relative order of deoxidizers as regards their various influences.*

Order of deoxidizer in regard to influence on[1]—	Fe-C-Ti.	Fe-Mn.	Fe-Ti, carbonless.	Fe-Si.	Al.
Density (Table 10)	1	5	2	4	3
Specific gravity (Table 11)	2½	4	1	5	2½
Soundness (Table 35)	4	5	3	2	1
Piping (Table 35)	1	4	5	2	3
Tensile strength, cast condition (Table 13)	2	3	4	1	5
Elongation, cast condition (Table 13)	1	3	5	2	4
Tensile strength, forged condition (Table 15)	2	3	4	1	5
Elongation, forged condition (Table 15)	4	5	2	3	1
Charpy test, cast condition (Table 16)	2	3	5	1	4
Charpy test, forged condition (Table 17)	5	3	2	4	1
Carbon segregation (Table 18)	2	1	3	5	4
Cost of deoxidizer per ton of steel (Table 34)	4	1	5	2	3

[1] The group of ingots with the smallest pipe is designated as No. 1.

For a direct comparison of the density and the specific gravity, the results given in Tables 10 and 11 are repeated below in Table 37, together with the mean of the two figures.

TABLE 37.—*Comparison of density and specific gravity figures.*

[Experiment 2.]

	Fe-C-Ti.	Fe-Mn.	Fe-Ti, carbonless.	Fe-Si.	Al.
Relative density (Table 10)	7.85	7.76	7.82	7.77	7.79
Specific gravity (Table 11)	7.769	7.753	7.773	7.746	7.769
Mean	7.81	7.757	7.79	7.758	7.78

SMOKELESS POWDER.

PHYSICAL TEST OF FOUR LOTS OF NITROCELLULOSE POWDER.

A sample from 1 grain of each lot was prepared for the physical test described on page 25, Ordinance Pamphlet No. 450, which reads as follows:

> Normal grains will be taken and both ends cut off at right angles to the length until $\frac{\text{length}}{\text{diameter}}=1$. These pieces are accurately measured for length, and then slowly compressed between parallel surfaces until the first crack appears. The pressure is then removed and the grain again measured. The decrease in length necessary to crack the grain is calculated to per cent of original length. The average compression must not be below 35 per cent.

The test was made on the large testing machine, and the force required to compress the samples was recorded for each 0.05-inch compression. The force required to compress the samples from the other three lots were recorded for each 0.01-inch compression. The results were as follows:

Sample.	Original length.	Compression.	Compression.
	Inch.	*Inch.*	*Per cent.*
A–12''....	0.790	0.39	49.3
B–12''....	.840	.39	46.3
C–14''....	.802	.400	49.8
D–12''....	.778	.33	42.4

The compressions were determined by measuring the movement of the heads of the machine and are somewhat higher than would be obtained by measuring the grains after removing the load, as in each case the grain expanded somewhat when the load was removed.

Each grain was compressed somewhat further than was required to produce the first crack.

Sample A developed four cracks, two of which lay in a plane through the center hole and passing about 10° from two opposite outer holes. One of the remaining cracks was in a plane through an outer hole and was consequently 80° from the first plane, and the other was about 60° on the other side of this plane, and was 20° from one of the outer holes.

Sample B developed one large crack about 10° from a plane passing through three holes.

Sample C developed two cracks 120° apart, and with the center hole each determined a plane bisecting the sides of a hexagon formed by joining the six outer holes.

Sample D developed two cracks lying in a plane passing through the center and two outside opposite holes.

In each lot of powder the cracks appeared at the outside only, and could in no case be traced as far in as the outer holes. It was

considered that the other grains intended for duplicating this test could be used to better advantage otherwise, and the test was not repeated.

Since the energy required to compress a grain until it cracked was about 150 foot-pounds, it was thought well to apply about one-third this amount of energy in the shock test.

A weight of 10 pounds was accordingly dropped 5 feet on a cylinder whose height was equal to its diameter prepared from a grain of sample C.

The sample was not broken and was but slightly compressed. Small cracks were developed in the grain, some of which radiated from the center hole and connected it with the outer holes and some of which connected outer holes or radiated from them toward the outer surface of the grain. The location of the cracks do not admit of a more accurate description.

It was evident that more energy should be applied for this test. It was noted that the character of the cracks developed was entirely different from that developed by the compression test in the testing machine.

In the shock test the cracks were in the center of the grain, and none was visible on the outside cylindical surface, while in the testing machine compression the cracks started on the outside only, and did not penetrate deeply.

A weight of 10 pounds was dropped 14 feet 5 inches on a sample of B. The energy absorbed by this grain was approximately the same as that required to compress a similar sample 0.39 inch in the testing machine. The grain was compressed about 0.11 inch, or less than one-third as much as the grain compressed in the testing machine.

One crack through the center and two opposite outside holes was plainly visible entirely across the upper end and from the two outside holes through the middle hole on the bottom end. In addition to this large crack on the top end, there was one extending from the central hole to one of the outer holes, making an angle of 60° with the large crack, and on the bottom there were two such cracks.

The general appearance of the grains subjected to a blow on the end would indicate a brittle interior held together by a tough skin.

A sample of A was then given the same test. The original length was 0.840 inch, and it was compressed 0.132 inch. Two cracks radiating from the center joined the central hole with outer holes on each end, but no crack extended further than the outer holes.

A sample of D was then given the same test. Original length, 0.798 inch; compression, 0.15 inch. Cracks radiating from the central hole to each of the outer holes and extending almost to the surface developed in this grain, and the cracks were more numerous and larger than in either of the other two samples tested at 14 feet 5 inches.

Judging by this test alone the C and D powders seemed more brittle than either of the other two.

The weight was then raised to 22 feet 11 inches, and dropped successively on the end of samples from each lot, with the following results:

Sample 'A, original length, 0.825 inch; compression 0.212 inch. Radiating cracks on each end from center hole to each of outer holes; one of these cracks extended beyond outer hole almost to surface of grain. In addition to the interior two exterior cracks developed on

opposite sides of the grain. The exterior cracks did not lie in the plane of any of the interior cracks and did run into them.

Sample B, original length, 0.852 inch; compression, 0.218 inch. One large crack extending entirely across the grain through central and two opposite outside holes top and bottom and completely dividing the grain into two parts, except for a small section on each side of the grain midway of its length. In addition, cracks radiated from the central hole to each of the outer holes, but did not extend beyond in any case.

Sample C, original length, 0.797 inch; compression, 0.265 inch. Crack radiating from the central hole and connecting it with most of the outer holes at both ends developed. One or two of these cracks extended beyond the outer holes, but none reached the outer surface of the grain.

Sample D, original length, 0.808 inch; compression, 0.277 inch. The description of the preceding sample applies to this one, except that the cracks were slightly larger and extended nearer the surface of the grain, although none reached the surface.

The end compression tests, both static and dynamic, failed to show any marked difference between the lots of powder examined, although the appearance of the grains of the lots C and D subjected to the dynamic test seemed to indicate that these powders were more brittle on the interior than were the other powders tested. This test alone is considered inconclusive.

In view of the results later obtained with grains subjected to a side compression test it is well to note here that about 150 foot pounds energy was required to compress a grain slowly until cracks developed, and the application of 220-foot pounds as a blow did not cause the grains to break apart.

A cylindrical specimen, the height of which was equal to its diameter, was then turned from a grain from each lot and subjected to a lateral compression test in the large testing machine. Each specimen was placed between the heads of the machine so that a plane through the central and two opposite holes was parallel to the axis of the machine. The results were as follows:

Sample A, original diameter, 0.790 inch:

Compression of 0.01 inch required a load of 500 pounds.
Compression of 0.02 inch required a load of 890 pounds.
Compression of 0.03 inch required a load of 1,120 pounds.
Compression of 0.04 inch required a load of 1,320 pounds.
Compression of 0.043 inch required a load of 1,360 pounds.

Cracked in a plane parallel to axis of machine and through central and two opposite holes. Compression stopped when crack developed and pieces did not fall apart.

Sample B, original diameter, 0.829 inch:

Compression of 0.01 inch required a load of 250 pounds.
Compression of 0.02 inch required a load of 750 pounds.
Compression of 0.029 inch required a load of 960 pounds.

Cracked in plane parallel to axis of machine and through central and two opposite holes. Pieces did not fall apart.

Sample C, original diameter, 0.779 inch:

Compression of 0.01 inch required a load of 300 pounds.
Compression of 0.02 inch required a load of 700 pounds.
Compression of 0.03 inch required a load of 890 pounds.
Compression of 0.036 inch required a load of 1,010 pounds.

Broke with considerable noise in plane parallel to axis of machine and through central and two opposite holes. One half of grain flew some distance when crack developed. The cleavage planes between adjoining holes in the break and between the outer holes and the outside of the grain were all parallel and inclined about 15° to the general direction of the line of break of the two halves. This phenomena was noted in several grains of lot D that were broken by lateral compression, and in this one grain of lot C. In all other grains cleavage planes were parallel to the general direction of the break.

Sample D, original diameter, 0.764 inch:

Compression of 0.01 inch required a load of 300 pounds.
Compression of 0.02 inch required a load of 700 pounds.
Compression of 0.026 inch required a load of 820 pounds.

This grain broke in a plane parallel to the axis of the machine and through the central and two opposite holes.

Arranged in order of toughness as indicated by this test the lots were A, C, B, and D. The energy required to develop a crack was about 1-foot pound as compared with 150-foot pounds in the end compression test.

A similar sample was prepared from B and a weight of 10 pounds dropped on the side of the sample from a height of 6 inches. The grain was broken.

A weight of 10 pounds was dropped from a height of 4 inches on samples of D and C, and it broke the grains.

Arrangements were then made to drop a weight of 1 pound from various heights on samples prepared as before. This weight was dropped in succession on samples from each lot from a height of 16¾ inches with the following results.

A.—No crack of any kind developed.

B.—Very small crack developed from one of outside holes to surface of grain for a short distance at one end. No other effects visible.

C.—Grain broke in two large pieces and two slivers.

D.—Grain broke into two large pieces and one sliver. Cleavage planes parallel and inclined 15° to general direction of break.

This weight was then dropped from a height of 25½ inches on a sample of each lot in succession with the following results:

A.—Cracked entirely across at one end. Crack extended almost the entire length of the grain.

B.—Grain had exactly the same appearance as the one from A.

C.—Broke into two large parts and one sliver.

D.—Broke into two large parts and some slivers. Cleavage planes inclined 15° to general direction of break.

While the tests up to the one described have indicated that C and D were perhaps slightly more brittle than the others, the result of this test enables us to say without hesitation that when subjected to lateral shock C and D are decidedly more brittle than the other two powders examined.

It was decided best to test the grains in the Charpy impact machine in their original condition rather than to turn them to true cylinders. The following results were obtained:

1st sample C = 59. 2 foot-pounds energy absorbed.
2nd sample C = 66. 6 foot-pounds energy absorbed.
1st sample D = 53. 7 foot-pounds energy absorbed.
2nd sample D = 35. 8 foot-pounds energy absorbed.

1st sample B = 102. 8 foot-pounds energy absorbed.
2nd sample B = 51. 05 foot-pounds energy absorbed.
1st sample A = 90. 9 foot-pounds energy absorbed.

On the second and third attempts to break a grain of A, the grain was cut in two pieces by the edge of the ax, and one piece wedged between an inclined part of the ax and the side of the frame and stopped the ax, so that no readings were obtained. This in itself indicates a tough powder.

This test, while not furnishing results entirely consistent, show in a general way that the C and D powders do not offer as much resistance in such a test as do the other two lots tested. This test is believed of doubtful accuracy as made, on account of the tendency of fragments to retard or entirely stop the ax after the grain had been shattered. The Charpy machine, it is believed, could be modified so as to overcome this difficulty.

After the discovery of the peculiar cleavage planes of powder D, an effort was made to discover indications of planes of weakness in this powder before it was submitted to any stress. None could be detected.

RÉSUMÉ.

(1) The relation between the energy required to crack a grain of powder by end and by lateral compression is apparently about 200 to 1. After making due allowance for the reduction in area on account of the three holes lying in the same plane, this indicates very poor bond or welding between adjacent longitudinal fibers.

(2) Since the resistance to lateral compression is the critical one, it is thought the powder specifications should be revised to provide for such a test for cannon powders.

(3) The Charpy impact machine affords a test indicative, in a general way, of the relative brittleness of powders. It is believed the machine might be modified so as to give consistent and satisfactory results.

(4) The simple expedient of dropping a weight of about 1 pound on the side of a powder grain affords a reliable and certain method of determining its brittleness.

(5) It is believed well established that of the four lots of powder lots C and D are comparatively brittle, and lots A and B are comparatively tough. It would be interesting to note which of these powders, if any, have given abnormally high pressures.

EXPERIMENT TO DETERMINE THE FEASIBILITY OF MAKING PHOTOMICROGRAPHS OF SMOKELESS POWDER GRAINS.

OBJECT.

The object of the herein-reported experiment was to determine the apparatus and arrangements necessary to make photomicrographs of smokeless powder grains.

CONCLUSIONS.

It was found that satisfactory photomicrographs could be obtained of smokeless powder grains, both by reflected and by transmitted light. By satisfactory photomicrographs is meant that the pictures obtained are good as to clearness, lighting effect, and detail. It seems probable that with sufficient study and investigation, an intelligent and valuable interpretation of the structures could be made, though this laboratory has made no effort at interpreting the structures.

GENERAL.

The following lots of smokeless powder were received from Picatinny Arsenal:

12 grains, Picatinny Arsenal, lot 134–1914, for 12-inch gun.
12 grains, Picatinny Arsenal, lot 164–1914, for 12-inch gun.
6 grains, X, lot 6–1905, for 12-inch gun.
24 grains, Picatinny Arsenal, lot 155–1914, for 3-inch field gun.
24 grains, Picatinny Arsenal, lot 156–1914, for 3-inch field gun.
24 grains, Y, lot 169–1914, for 3-inch field gun.
24 grains, Y, lot 170–1914, for 3-inch field gun.

MICROSCOPE.

The microscope with which the attached photomicrographs were made is a Leitz micrometallograph equipped with a photomicrographic camera. It is the instrument regularly used in this laboratory for metallographical investigations. Photograph No. 1 shows this microscope. There are on the market several makes of microscopes equipped for photographic work, with which it is believed satisfactory results could be obtained.

Seven photomicrographs of powder grains are attached hereto. Nos. 2, 3, and 4 were taken with reflected light, while Nos. 5, 6, 7, and 8 were taken by transmitted light. In taking those by reflected light the Leitz instrument was arranged as shown in photograph No. 1 with the mirror M and its support removed. In taking photomicrographs Nos. 5, 6, 7, and 8 by transmitted light, however, the mirror M was used. The adjustable arc A was elevated so that it threw a horizontal beam on the mirror. This beam was reflected vertically through the specimen into the microscope. The prism illuminator P used for illuminating the specimen by reflected light was removed when examination was made by transmitted light.

PREPARATION OF SPECIMENS.

The preparation of the specimen is a very important process, whether the examination is to be by transmitted or reflected light. After numerous trials it was found that the best method of producing a satisfactory surface for microexamination was by polishing the specimen in a manner similar to that used in preparing metallic specimens. For examination by reflected light, the powder grain was turned or planed to a smooth surface. It was then successively polished with XF alundum, levigated alumina, and best grade jeweler's rouge, being polished with each abrasive until the scratches left by the preceding one had been eliminated. This laboratory is equipped with a special machine for polishing, on which the various abrasives, made up with water to a thick paste, are carried on horizontal disks rotating about 1,000 revolutions per minute. The specimen is held in light contact with each disk in turn until the proper degree of polish is obtained. In lieu of a polishing machine, a satisfactory polish can be obtained by hand polishing on broadcloth pads carrying the above-named abrasives in the form of a paste.

Specimens for examination by transmitted light were prepared by first turning off very thin slices in a lathe. These were then polished on both sides as before described, being held by means of a small countersunk piece of steel made for this purpose. The specimens which were prepared by this method were 0.020 inch thick.

One difficulty exprienced in the polishing was that if too great pressure was exerted on the specimen while in contact with the polishing disks, a chemical change took place on the surface of the powder grain with the appearance of a yellowish film.

DESCRIPTION OF PHOTOMICROGRAPHS.

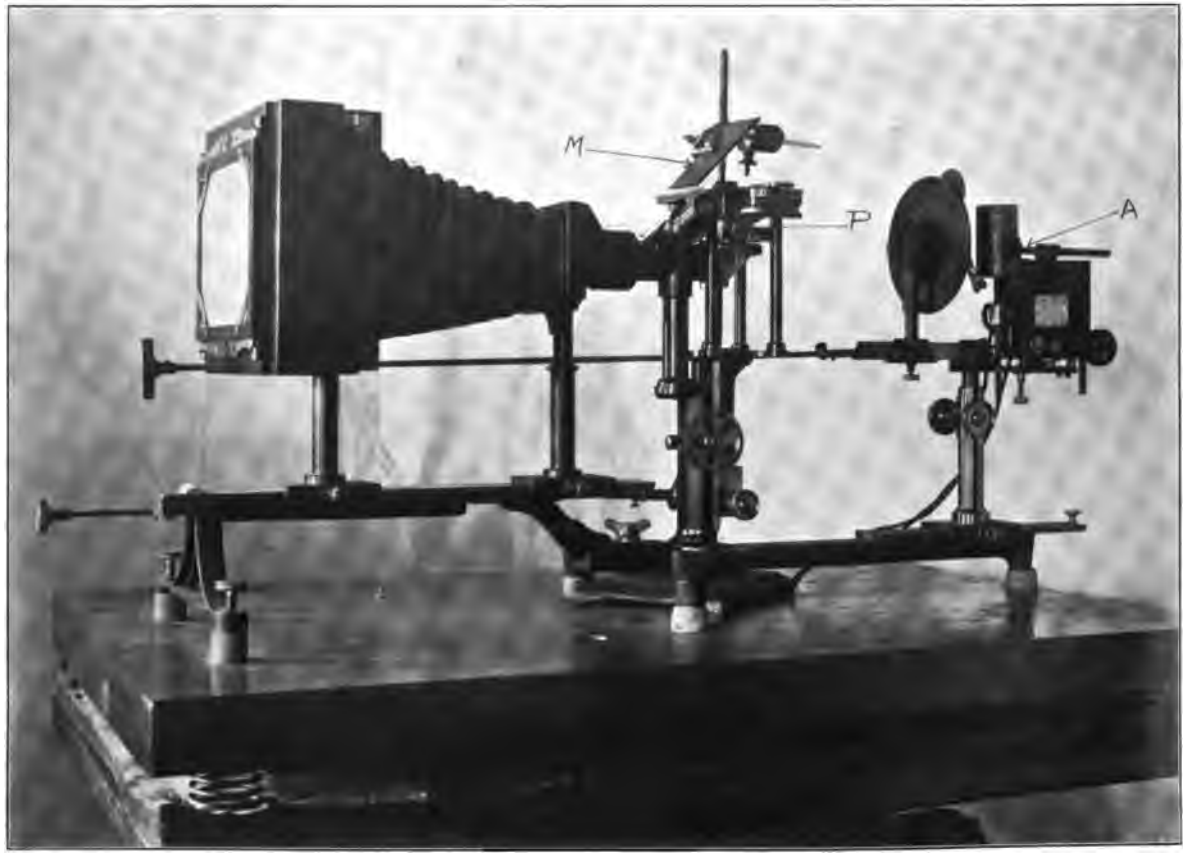
Photomicrograph No. 2 shows a cross section of a light-colored grain from lot No. 164. It was taken after the specimen had been polished with rouge. A well defined structure is apparent.

Micrograph No. 3 shows a longitudinal section of a similar grain to No. 2, polished but not etched. A distinct structure is also apparent in this picture.

Micrograph No. 4 shows a longitudinal section of a dark grain from lot No. 134. This specimen was polished in the usual manner and subsequently rubbed on a broadcloth pad saturated with ether and alcohol. This process resulted in a sort of polish attack.

Micrographs Nos. 5 and 6 were taken by transmitted light from a thin section of a light-colored grain from lot No. 164. The specimen was 0.020 inch thick, and polished on both sides. Micrograph No. 5 was focused on the lower surface of the section. Micrograph No. 6 was focused to get the clearest image. On account of the thickness of the specimen it is difficult to get a sharp image at this magnification.

Micrographs Nos. 7 and 8 were taken by transmitted light from a thin section of a dark colored grain from lot No. 134, prepared and polished in the same way as specimen No. 5. No. 7 was focused on the lower surface of the section, while No. 8 was focused to get the clearest image.



PHOTOGRAPH NO. 1.
Leitz Micrometallograph.

MICROGRAPH NO. 2.

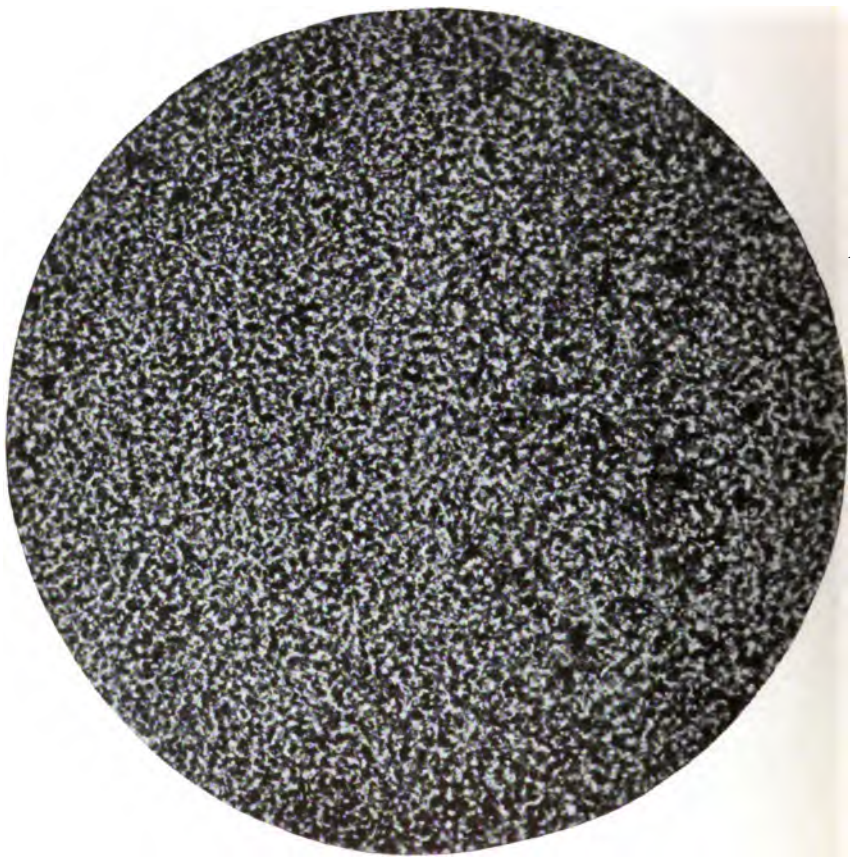
Magnification 75 diameters. Cross section of light-colored grain from lot 164. Polished and not etched. Specimen No. 2. Taken by reflected light.

MICROGRAPH NO. 3.

Magnification 75 diameters. Longitudinal section of light-colored grain from lot 164. Polished and not etched. Specimen No. 3. Taken by refected light.

MICROGRAPH NO. 4.

Magnification 75 diameters. Longitudinal section from dark-colored grain from lot 134. Specimen No. 4. Prepared by polish attack with ether and alcohol. Taken by reflected light.



MICROGRAPH NO. 5.

Magnification 75 diameters. Thin cross section of light-colored grain from lot 164. Specimen No. 5. Polished on both sides and .020-inch thick. Taken by transmitted light and focused on lower surface of specimen.

MICROGRAPH NO. 6.

Magnification 75 diameters. Same as micrograph No. 5, but focused to get clearest image.

CARTRIDGE BRASS.

EXAMINATION OF CARTRIDGE BRASS.

The following material was received for investigation:

10 cartridge cases, unfired and split, made from a reported bad lot of brass.
2 pieces sheet brass from good lot.
2 pieces sheet brass from bad lot.
1 piece sheet brass showing split.
2 semifinished cases annealed and water cooled.
2 semifinished cases annealed and air cooled.
3 cartridge cases fired—primers dropped out.
3 cartridge cases fired—primers did not drop out.
3 cartridge cases from bad lot unfired but primed.
3 cartridge cases from bad lot unfired and unprimed.
1 sample of primer composition.

Two reports with accompanying photomicrographs were likewise received.

An examination of the good and bad lots of sheet brass was made chemically and microscopically. The analysis as determined by this laboratory is as follows:

	Good.	Bad.
Copper.....	67.04	66.90
Lead.....	Trace.	Trace.
Iron.....	.08	.10
Zinc.....	32.72	32.80

These results are a trifle lower in copper than those of the reports received, but the samples were not the same. The composition gives no indication as to the cause of the trouble.

Microscopic examination revealed nearly identical crystalline structures for the good and the bad lots of metal. The crystalline structure was a trifle finer in the bad metal than in the good, though no significance in explaining the present difficulty can be attached to this fact. The scleroscope showed a hardness of 25 for both lots of metal. The universal hammer was used in the instrument in making all hardness tests.

Microscopic examination was next made of 10 cartridge cases, unfired, from the bad lot; 3 cartridge cases, fired, from which primers dropped, and 3 cartridge cases, fired, from which primers did not drop out. These cartridge cases were all split longitudinally and polished on the exposed section. They all showed the same characteristic structure, and no difference could be detected between any of them. This characteristic structure is shown in photographs 1 to 5.

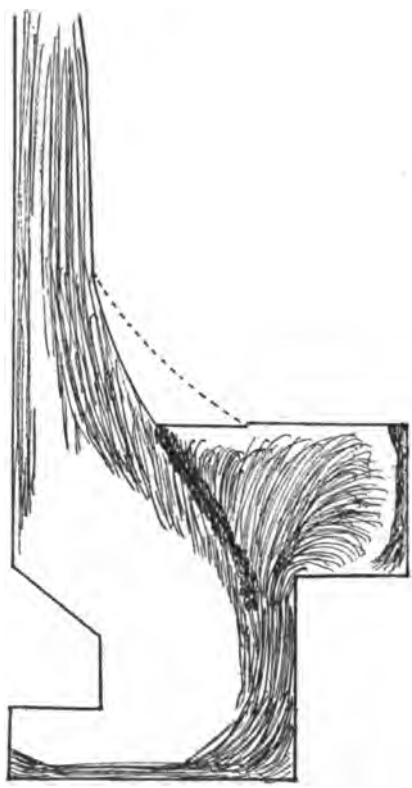
Photograph No. 1 shows quite plainly the structure visible to the eye which is developed by etching. This photograph is taken at 3½ diameters, and the line running from the corner of the powder

PHOTOGRAPH NO. 1. (×3½.)

PHOTOGRAPH NO. 2. (×12.)

chamber to the corner of the primer pocket may be readily seen. This line is characteristic of all the cases examined, and it consists of a band of badly strained metal. This band of overstrained metal and the direction of the lines of flow may be seen in photograph No. 2, which is taken at 12 diameters.

Sketch No. 1 will perhaps show more clearly the location and comparative areas of the overstrained metal. This sketch is similar to photograph No. 2, viz, a section of half of the primer end of the case. The shaded portion represents the strained metal, while the unshaded part was not badly overworked. The comparative microscopic appearance of overworked and of annealed metal may be seen by comparing photograph No. 4 with photograph No. 7. The former is overworked, and we might say amorphous, the latter is the normal crystalline structure resulting from annealing.



Sketch No 1

At the end of this band of strained metal nearest the powder chamber there was invariably found a small crack starting from the corner of the powder chamber, and extending toward the corner of the primer pocket. The character of this crack is shown in photographs Nos. 3, 4, and 5. Nos. 3 and 4 were taken at 75 diameters, No. 3 before etching, and No. 4 from another case after etching. Photograph No. 5 is the same as No. 4 at higher magnification, viz, 400 diameters. This crack is an actual separation of the metal, probably a lap formed in the heading and pocketing operation when the bottom surface of the powder chamber is changed from concave to flat, as shown in photograph No. 6.

The examination of these 16 cartridge cases which were sectioned through the head revealed the presence in them all of the above-described badly strained metal and incipient cracks. It is quite probable that this condition is an important factor in the present difficulty. It would be interesting to know if this condition of the metal existed in the cases made before the heading and pocketing operations were combined. It is believed that if the corner at the bottom of the powder chamber were filleted slightly more, as shown dotted in sketch No. 1, a stronger case would result, and one less likely to allow spreading of the primer pocket.

In connection with one of the reports received, a micrograph was submitted, which shows a streak across it. It was suggested that this streak is a line of internal cracks, probably produced by excessive powder pressure during firing. In none of the 10 unfired, nor the 6 fired cases examined here, was such a streak discovered. However, a somewhat similar streak was found in a semifinished case which was split longitudinally, polished, and examined after the third draw. Photographs No. 7 and No. 8 show this streak at 75 and 400 diameters.

It is believed that this streak is the result of local segregation of lead, and no evidence has been obtained at this arsenal that the difficulty under investigation might be attributed to such streaks. In this connection, regarding the statement made that "lead always appears uniformly distributed across the face of the crystal grains instead of between the intercrystalline boundaries," we desire to quote from Bengough & Hudson's article on the heat treatment of brass,[1] 70–30 alloy, as follows:

Effect of lead.—The presence of lead is indicated by small, more or less rounded particles scattered through the crystals. When brass containing lead has been annealed at a very high temperature, there is a tendency for the lead to segregate between the crystals, and this effect seems to increase with the time of annealing.

As regards the rate of cooling of cartridge brass from the annealing temperature, we believe that variation in the rate of cooling will make no appreciable difference in tensile properties, hardness or grain structure. In order to determine exactly what effect there might be, two pieces of cartridge brass from the lot marked "good" were heated to 650° C. They were held at heat 15 minutes, then one was quenched in water, the other was air cooled. The tensile values and scleroscope hardness are appended.

Marks.	Width.	Thickness.	Sectional area.	Tensile strength.		Elongation in 2 inches.	
				Load.	Stress per square inch.		
	Inch.	*Inch.*	*Sq. inch.*	*Pounds.*	*Pounds.*	*Inches.*	*Per cent.*
Air	0.502	0.122	0.0612	2,856	46,660	1.33	66.5
Water	.498	.120	.0598	2,780	46,480	1.23	61.5

At fracture:

Marks.	Elongation in inch sections.		Width.	Thickness.	Sectional area.	Contraction of area.	Appearance of fracture.	Scleroscope hardness No.
	Inch.	*Inch.*	*Inch.*	*Inch.*	*Sq. inch.*	*Per cent.*		
Air	0.62	[1] 0.71	0.33	0.08	0.026	57.3	Light yellow	15
Water	.49	[1] .74	.33	.08	.026	55.9	....do....	15

[1] Inch section in which fracture occurred.

Microexaminations were made of semifinished cases which were air and water cooled after annealing. They showed practically identical grain structures. The scleroscope hardness of each was 12.

[1] Jour. of the Inst. of Metals, Vol. 4, 1914. P. 106.

PHOTOGRAPH NO. 3. (×75.)

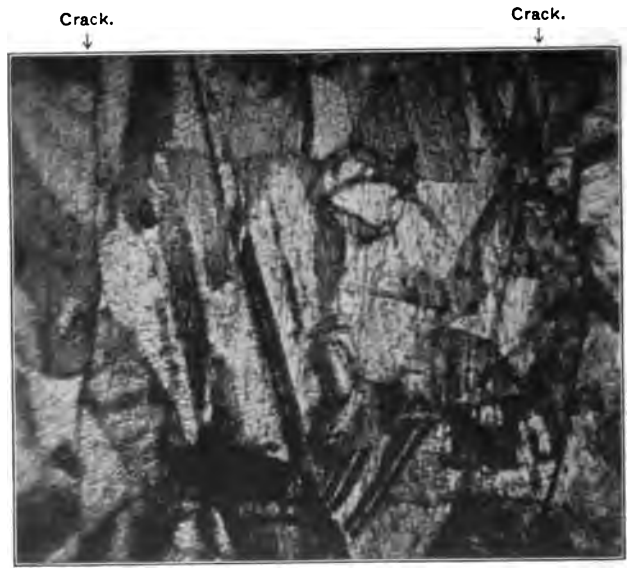
PHOTOGRAPH NO. 4. (×75.)

PHOTOGRAPH NO. 5. (X400.)

PHOTOGRAPH NO. 6.

PHOTOGRAPH NO. 7. (X75.)

PHOTOGRAPH NO. 8. (X400.)



PHOTOGRAPH NO. 9. (X400.)

In connection with the inquiry as to what is the effect of the original temper of sheet cartridge brass after it has been once annealed, we can say that there is practically no effect, provided the metal is cold worked before annealing. By cold working the crystalline structure is distorted. The annealing allows recrystallization to take place and the crystal size after annealing will depend primarily on the temperature of the anneal. Practically the only thing dependent on the original temper of the metal is the amount of cold work which can be put on it before annealing.

The piece of sheet metal showing a split was examined and photograph No. 9 was taken at 400 diameters.

Two cracks or splits are visible. It is probable that these were originally blowholes in the ingot which failed to weld up and became flattened out in the sheet.

SUMMARY.

While the definite cause of the present difficulty has not been surely discovered, evidence has been brought forth which shows that the metal in the head of the cases is in a badly overworked state. The probabilities are that this condition has a considerable bearing on the trouble. The metal has been overworked to an extreme at this point, and it is recommended that steps be taken to overcome this condition.

Suggested methods for helping to remedy the trouble are:

(1) Separate the heading and pocketing operations.

(2) Change the shape of the powder chamber so as to allow a larger fillet between the wall and base of same.

(3) Install methods to insure accurate control of time and temperature in the annealing operations.

MICROSCOPIC EXAMINATION OF CARTRIDGE CASES AFTER SUCCESSIVE STAGES OF MANUFACTURE.

Specimens representing 15 successive steps in the manufacture of cartridge cases were received. These were split longitudinally, polished, etched with ammoniacal hydrogen peroxide, and examined under the microscope. Photomicrographs were not taken, but a description of the microstructure in each case is submitted, together with photographs of the split cases after etching. Table showing description and photographs are appended.

SUMMARIZING.

Except for the cases noted below, the various operations seem to be satisfactory and the condition of the metal to be good. In the pocketing operation the bottom of the powder chamber is changed from concave inward to flat, and at that time small laps or cracks are found between the wall and base of the powder chamber. These cracks persist and even become enlarged during the succeeding operations. Steps should be taken to prevent the formation of these during the pocketing operation. The cumulative effect of the cold work done on the metal during the fourth and fifth draws, the pocketing, the heading, and the venting operations puts the metal in the head in a bad state of overstrain. We would recommend the introduction of a 1,200° F. anneal after the pocketing operation.

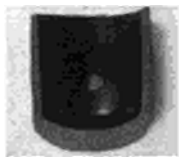
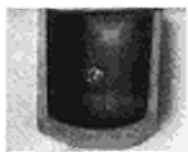
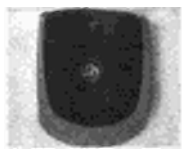
CONCLUSION.

The present operations are satisfactory except that—

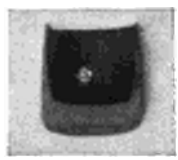
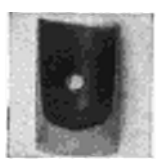
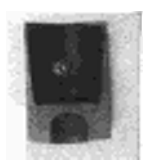
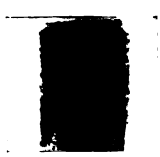
First. Steps should be taken to eliminate the formation of a lap or crack between the wall and the bottom of the powder chamber during the pocketing operation.

Second. The cases should be annealed at 1,200° F. after the pocketing operation.

MICROEXAMINATION OF CARTRIDGE BRASS DURING THE VARIOUS STAGES OF MANUFACTURE INTO CARTRIDGE CASES.

No.		
1. Cup before annealing.		Fairly fine grained across base. Crystals become drawn out and amorphous at sides where the drawing was done. Twin crystals.
2. Cup after annealing at 1,400° F. 1st anneal.		Fairly coarse crystals over whole section. Effect of drawing eliminated. Anneal rather high. Twin crystals.
3. First draw before annealing. 1st draw.		Amorphous metal in sides. Medium coarse crystals in base, slightly amorphous along edges. Twin crystals.
4. First draw after annealing at 1,350°-1,375° F. 2nd anneal.		Medium coarse crystals all over. Effect of cold work entirely eliminated. Twin crystals.
5. Second draw before annealing. 2nd draw.		Base medium coarse twin crystals slightly crushed at front and rear. Walls finer crystalline tending toward amorphous metal at front.
6. Second draw after annealing at 1,350° F. 3rd anneal.		Base medium coarse twin crystals. Walls fine twin crystals. Effect of cold work eliminated.
7. Third draw but not bumped and not annealed. 3rd draw.		Base medium coarse twin crystals. Walls amorphous. Small area in base near wall similar to area described in previous report, probably segregated lead.
8. Third draw and bumped but not annealed. 3rd draw and bump.		After bumping, in middle of base medium coarse twin crystals. Lines of strained crystals extend from near edge of base to corner of powder chamber. Walls amorphous.

MICROEXAMINATION OF CARTRIDGE BRASS DURING THE VARIOUS STAGES OF MANUFACTURE INTO CARTRIDGE CASES—Continued.

No.		
9. Third draw, bumped and annealed at 1,250° F. 4th anneal.		Medium to fine twin crystals in base and walls. All evidence of strain eliminated.
10. Fourth draw. No anneal.		Base medium coarse twin crystals. Amorphous walls.
11. Fifth draw. No anneal.		Base medium coarse twin crystals. Walls more amorphous than in 10.
12. Pocketing. No anneal.		Metal badly cold worked around primer pocket and especially between primer pocket and powder chamber. Line of strained metal extending from primer pocket to corner of powder chamber. Incipient cracks at corner of powder chamber extending toward primer packet. Recommend changing punches to eliminate the formation of crack, and also anneal after this operation.
13. Heading. No anneal.		Strained condition of metal in head increased and incipient cracks—are perhaps somewhat enlarged.
14. Piercing or venting. No anneal.		Practically no change in condition of metal.
15. Head trim. No anneal.		Shows strained metal and crack as in previous report.

PRIVATE TESTS.

PRIVATE TESTS.

Tests made during the fiscal year ended June 30, 1915.

Date.	Material.	Name.	City and State.
1914.			
July 16	Concrete cubes	Town of Westfield	Westfield, Mass.
17	Steel	Savage Arms Co	Utica, N. Y.
17	Partition blocks	Bradford Fireproofing Co	Bradford, Pa.
17	Hollow tiles	A. Lyth & Sons Co	Buffalo, N. Y.
20	Spark plugs	Randall-Miller Co	Boston, Mass.
22	Columns and brackets	United States Column Co	Cambridge, Mass.
23	do	do	Do.
27	Steel	Savage Arms Co	Utica, N. Y.
27	Concrete building blocks	The Bridgeport Stone Co	Bridgeport, Conn.
28	Babbitt	Sauveur & Boylston	Cambridge, Mass.
28	Column	Gutterson & Gould	Portland, Me.
30	Steel	Savage Arms Co	Utica, N. Y.
31	Shrapnel cases	The Carpenter Steel Co	Reading, Pa.
Aug. 3	Shackles	Fletcher & Crowell	Portland, Me.
7	Steel	United Steel Co	New York, N. Y.
8	Hollow tiles	A. Lyth & Sons Co	Buffalo, N. Y.
20	Red brick	Boston Brick Co	Boston, Mass.
31	Steel	Savage Arms Co	Utica, N. Y.
Sept. 2	Concrete building blocks	R. W. Prescott	Danvers, Mass.
9	Interlocking tiles	Central Clay Products Co	North Tonawanda, N. Y.
9	Jasper cube	W. J. Sullivan	Boston, Mass.
18	Steel	Potter & Johnston Mach. Co	Pawtucket, R. I.
19	Column	Thomas Allen	Somerville, Mass.
19	Concrete building bricks	The Bridgeport Stone Co	Bridgeport, Conn.
24	Wrought iron	The Crandall Engineering Co	East Boston, Mass.
24	Cement bricks	W. E. Harrington	Salem, Mass.
24	Concrete building block	J. M. Ellis & Sons	Woburn, Mass.
24	Jasper	W. J. Sullivan	Boston, Mass.
25	Steel rails	Barbour-Stockwell Co	Cambridge, Mass.
26	Steel	Erie Forge Co	Erie, Pa.
30	Draft gears and spring plates	Standard Coupler Co	New York, N. Y.
Oct. 1	Malleable iron barrel	do	Do.
3	Iron cylinders	do	Do.
13	Shrapnel case metal	Potter & Johnston Mach. Co	Pawtucket, R. I.
14	Rubber belting	Revere Rubber Co	Chelsea, Mass.
15	Brackets on columns	United States Column Co	Cambridge, Mass.
16	Columns	do	Do.
19	Draft gear	Standard Coupler Co	New York, N. Y.
20	Bricks	Sol. Lenzner	Buffalo, N. Y.
20	Hollow tiles	Lyth Tile Co	Do.
21	Concrete building blocks	Winchester Concrete Co	Winchester, Mass.
23	Chain	The Bridgeport Chain Co	Bridgeport, Conn.
23	Interlocking tiles	Central Clay Products Co	North Tonawanda, N. Y.
29	Concrete building block	Nicol Bertuccio	Salem, Mass.
29	do	Winchester Concrete Co	Winchester, Mass.
30	do	Giuseppe Cardone	Salem, Mass.
Nov. 12	Cement building block	Waterproof Cement Block Co	Do.
14	Chain	Crandall Engineering Co	East Boston, Mass.
17	Hollow tile	Lyth Tile Co	Buffalo, N. Y.
17	Concrete building blocks	Winchester Concrete Co	Do.
20	do	Waterproof Cement Block Co	Salem, Mass.
24	do	Giuseppe Cardone	Do.
30	do	Bessie Fitzpatrick	Gardenville, N. Y.
Dec. 3	do	Giuseppe Cardone	Salem, Mass.
4	Italian hemp lines	The Lincoln-Dillaway Co	Boston, Mass.
12	Boiler plates	Prof. Chas. H. Chase	Do.
14	Concrete building blocks	August R. Schultz	Salem, Mass.
14	Shackles	Fletcher & Crowell	Portland, Me.
16	Marble cubes	Vermont Marble Co	Proctor, Vt.
16	Concrete building block	Giuseppe Cardone	Lawrence, Mass.
18	Steel	Savage Arms Co	Utica, N. Y.
19	Concrete building	Louis Miller	Salem, Mass.
30	Steel	Savage Arms Co	Utica, N. Y.
30	Cement bricks	J. S. Nelson & Son	Salem, Mass.
31	Draft gear	Standard Coupler Co	New York, N. Y.

Tests made during the fiscal year ended June 30, 1915—Continued.

Date.	Material.	Name.	City and State.
1915.			
Jan. 5	Concrete building block	Waterproof Cement Block Co.	Salem, Mass.
6	Steel	Savage Arms Co	Utica, N. Y.
7	Hooks, swivels, and missing links.	The Thos. Laughlin Co	Portland, Me.
13	Hollow tiles	Pennsylvania Fireproofing Co.	Erie, Pa.
16	Concrete-filled column	Milford Iron Foundry	Milford, Mass.
21	Hemp lines	Smith & Dove Mfg. Co	Andover, Mass.
25	Steel	Savage Arms Co	Utica, N. Y.
26	Steel casting	Plymouth Cordage Co	North Plymouth, Mass.
26	Boiler plate	Prof. Chas. H. Chase	Boston, Mass.
Feb. 1	Steel	Savage Arms Co	Utica, N. Y.
3	Concrete-filled column	Somerville Column Co	Somerville, Mass.
4	Steel	National Tube Co	Pittsburgh, Pa.
6	Riveted joints	Prof. Chas. H. Chase	Boston, Mass.
12	Belting	The Carton Belting Co	Do.
13	do	do	Do.
16	Steel	Savage Arms Co	Utica, N. Y.
24	do	Scovill Mfg. Co	Waterbury, Conn.
24	Granite cube	Hillsborough Granite Co	Nashua, N. H.
24	Hollow tiles	A. Lyth & Sons Co	Buffalo, N. Y.
Mar. 2	Brick piers	Littleton Unit Brick & Tile Co. (Inc.).	Boston, Mass.
6	Concrete building	Winchester Concrete Co	Winchester, Mass.
13	Floor tiles	H. L. Beehler	Waltham, Mass.
16	Manila rope	Metropolitan Water & Sewerage Board.	Boston, Mass.
18	Hollow tile	A. Lyth & Sons Co	Buffalo, N. Y.
19	Concrete building blocks	Louis Miller	Salem, Mass.
23	Steel	John W. Mitchell	Boston, Mass.
30	do	Scovill Mfg. Co	Waterbury, Conn.
31	do	Halcomb Steel Co	Syracuse, N. Y.
Apr. 2	Cement building block	Olsen Bros	Buffalo, N. Y.
10	Boiler plate	International Engineering Works (Ltd.).	Framingham, Mass.
12	Steel	John W. Mitchell	Boston, Mass.
14	do	Savage Arms Co	Utica, N. Y.
26	do	C. H. Cowdrey Mach. Works	Fitchburg, Mass.
28	Manila rope	Great Northern Paper Co	Bangor, Me.
May 1	Bricks	New England Brick Co	Boston, Mass.
1	do	Building Department	Brookline, Mass.
1	do	Wm. J. McCarthy Co	Somerville, Mass.
3	Wire rings	Hood Rubber Co	Watertown, Mass.
5	Draft gears	Standard Coupler Co	New York, N. Y.
18	Brackets and cap on column	United States Column Co	Cambridge, Mass.
21	Hollow tiles	A. Lyth & Sons Co	Buffalo, N. Y.
21	Concrete building block	Ulderico Rapolli	Malden, Mass.
21	do	Giuseppe Cardone	Salem, Mass.
21	do	Frank Dangredo	West Watertown, Mass.
June 3	do	Giuseppe Cardone & Co	Lawrence, Mass.
3	Cement building block	Waterproof Cement Block Co.	Salem, Mass.
3	Concrete building block	F. Lundergan	East Lexington, Mass.
3	do	M. M. Dyer	Medford, Mass.
9	Steel	Prof. Albert Sauveur	Cambridge, Mass.
11	Shackles	Fletcher & Crowell Co	Portland, Me.
14	Hollow tiles	Lyth Tile Co	Buffalo, N. Y.
15	Column	United States Column Co	Cambridge, Mass.
15	Concrete building block	New Bedford Waterproof Concrete Building Block Co.	New Bedford, Mass.
15	Sand-lime bricks	Boston-Berkshire Composite Brick Co.	Boston, Mass.
24	Concrete building block	Tony L. Dispoli	E. Watertown, Mass.
24	Cast iron	Davis & Farnum Mfg. Co	Waltham, Mass.
25	Buoy shackles	Fletcher & Crowell Co	Portland, Me.
29	Flexner	E. R. Taylor	Boston, Mass.
30	Steel	Crucible Steel Co. of America	Harrison, N. J.

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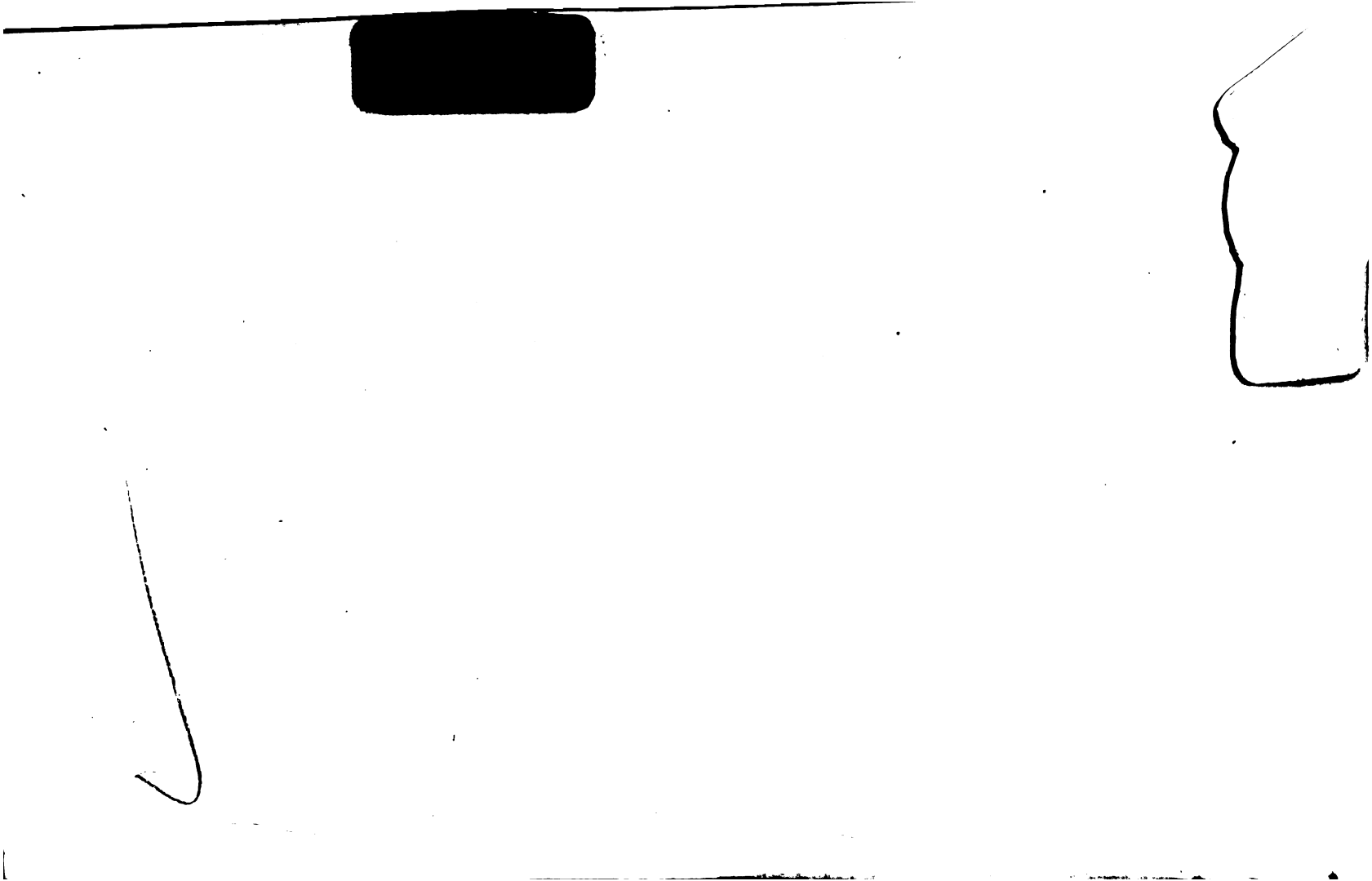
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